1996

Designing Products for End-of-Life

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DESIGNING PRODUCTS FOR END-OF-LIFE

BY

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

MANUFACTURING ENGINEERING

UNIVERSITY OF RHODE ISLAND

1996

MASTER OF SCIENCE THESIS

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UNIVERSITY OF RHODE ISLAND

1996

Abstract

What should the manufacturer or consumer do with their products at the end of their useable life? Providing economically and environmentally acceptable answers to this waste management question is becoming an important decision factor among product manufacturers in their choice of materials. The objective of this research was to help guide manufacturers to those answers through the investigation of how material selection affects the alternatives for what can be done with a product at the end of its useable life.

A classification system was developed to identify the preferred end-of-life destinations for the assembly components of a product based on their material content. The end purpose of this system is to assist in the recommendation of which materials should be separated from each other for optimum reprocessing or disposal. It will also assist in the selection of part materials during product design by helping to consider their future disposal after the completion of their intended use. This research also investigated, in depth, the end-of-life opportunities for the reuse of recycled plastics in manufacturing.

Acknowledgments

I would like to express my deepest gratitude to the following people, without whose support this research would not have reached its successful end:

- Dr. Winston Knight for his guidance and support throughout this research, as well as for his valued friendship (and giving me the opportunity to learn a bit about sailing).
- The members of my thesis and defense committee, Dr. Thomas Rockett, Dr. Peter Dewhurst, and Dr. Philip Datseris, who have also provided valued insight.
- My friend Prof. Jon Freckleton of the Rochester Institute of Technology for his persistence in convincing me to pursue a master's degree in engineering.
- All the members of the IME Department, for providing me with the opportunity to pursue a master's degree, and for all the assistance you gave me as I did so.
- Marty Davey of the Rhode Island Department of Environmental Management for her assistance, insight, and most importantly her patience.
- Jeffrey Young and his computer prowess, which helped to automate the classification system and to expedite my case study analyses.
- Andrew Abbott, friend and fellow graduate student, for his perspectives on our concurrent research, for his help with my case studies, for his humor, and for helping me to keep my sanity.
- My fellow graduate students for their insights, friendship, and for making my time at URI one which will be most memorable: Peter Hardro, Tuomo Harjula, Brian Rapoza, Veit Roskamp, Feng Sun, and Zhongwei Wang...

- And finally... My loving and supportive family who have always been there for me, provided the opportunities for me to achieve all that I desired, and continue to have a valued presence in my life.

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Chapter One: Introduction

1.1 Background

The disposal of solid waste is an environmental problem of increasing burden. In a study conducted by the National Solid Waste Association, it was found that 75% of the current landfill capacity will have been filled within the next ten years. It was also found that the amount of waste disposed per person has nearly doubled over the last twenty years [1]. As landfill capacity continues to decrease, so has the number of available landfills, which can be seen from Figure 1.1. Although the amount of material diverted from main stream waste for material or energy recovery has increased, approximately 61% of municipal solid waste was still disposed of in landfills in 1994 (Figure 1.2).

Figure 1.1: Number of Landfills in the United States [2]

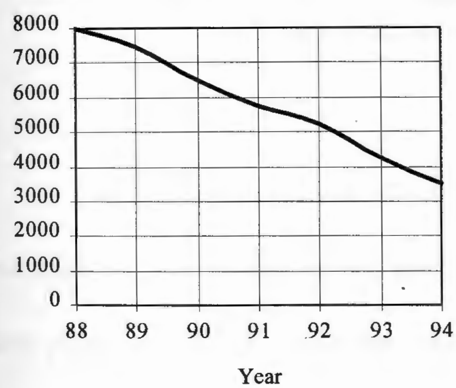
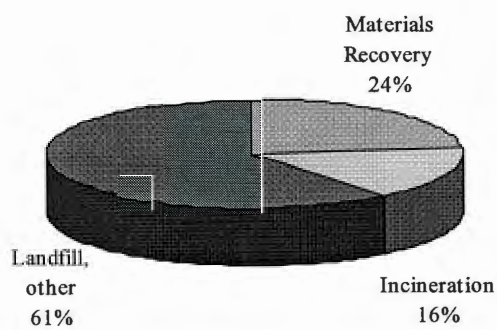
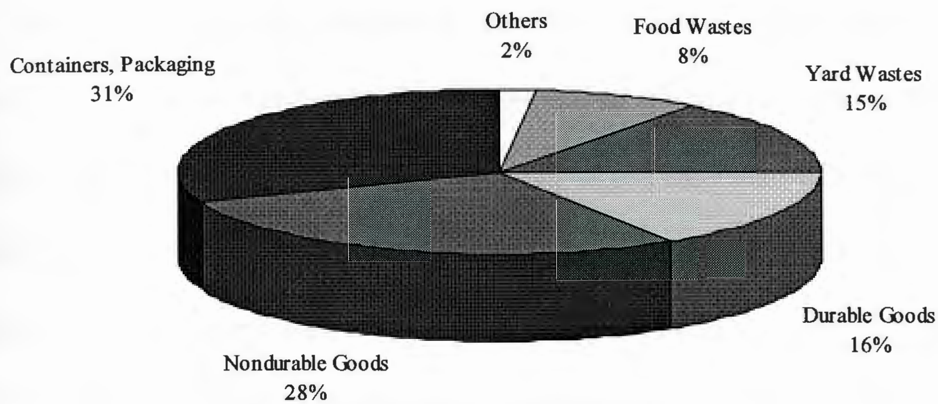


Figure 1.2: Municipal Solid Waste Management Characterization, 1994 [3]



To alleviate the situation of decreasing landfill capacity, legislation and better alternatives to the landfilling of solid waste have been considered. As a result, government regulations on the disposal of products have become more stringent. In many cases, manufacturers are being forced to take back their products (primarily durable goods) after the completion of their usable life. Durable goods accounted for approximately 16% of municipal solid waste in 1994 (Figure 1.3) and are easy targets for legislation, due to their size, visibility, and the ease of tracing them back to the manufacturer. Also, growing customer awareness of environmental issues is pushing manufacturers to produce more environmentally friendly products to meet those customer preferences [5].

Figure 1.3: Composition of Municipal Solid Waste in the United States, 1994 [4]



Following these trends of increasing legislation and public pressure, manufacturers of durable goods are looking more closely at the environmental impacts of their products. This has become especially true as more manufacturers have to take back their products and assume direct responsibility for their disposal. Therefore, manufacturers are interested in finding ways to optimize the disposal of their products, to lessen the burden on themselves and the environment.

To optimize product disposal, manufacturers need to consider the different disposal options (end-of-life destinations) that are available. Many manufacturers may be unaware of all the end-of-life destinations which can be employed for a given material, and which of those are preferred. As a result, they are prone to consider disposal options for their products that are familiar to them, while possibly neglecting more practical, environmentally friendly, or economical options as a result. They also need to consider how combinations of materials and additives in their products affect the quality and feasibility of certain disposal options. The manufacturer may need to separate or process certain parts in the assembly in order to utilize those options.

The classification system generated from this research will help optimize product disposal by providing information on the suitable end-of-life destinations for different types and combinations of materials. It will also point out, by means of a ranking system, the preferred end-of-life destination for those materials. This system will allow manufacturers to quickly evaluate how to dispose of their products, and which parts in them should be removed or grouped together to optimize the process.

The main focus of the recent environmental initiatives, as previously implied, has been to divert materials from landfills and collect it through recycling or reclaim programs. However, for material collection to be an effective alternative, end-use markets must exist which can use the material. The collection, recycling, and reuse of post-consumer metals, glass, and paper have become relatively common. Their relative ease of recycling also allows for closed-loop recycling within many applications. End-use markets are more readily available for those three materials and in many cases are cost competitive. Therefore, little need for developing end-use markets for these materials exists.

Plastics, however, represent a diverse family of polymeric materials. There are many different types of plastic resins, as well as many different fillers and additives to blend into them. As a result, the amount of possible plastic formulations is unlimited.

While this diversity makes plastic a versatile material, the distinct physical and chemical properties of each different formulation make plastic recycling difficult. The incompatibility that exists between many different plastics in recycling processes requires the separation of the plastics into distinct resin types. Other concerns with the recycling and reuse of plastics are contamination, quality and variation of material properties, and the quantities and varieties of recycled plastics available. The inherent limitations involved with recycling plastics are why the development of end-use markets needs special consideration and why they will be investigated as part of this research.

1.2 Related Research

There has been similar research conducted in both the areas of end-of-life destinations and end-use markets for recycled materials. In research conducted by Trolio [6], a model for an end-of-life classification system was proposed. The methodology that was developed, however, is inefficient and severely limited for the purpose for which it was designed. The methodology is only capable of telling dismantlers which end-of-life destinations are possible for a given material or combination. It does not provide any information on which end-of-life destinations are preferred, or provide a level of preference (practicality) within each of those destinations. It also does not take into account the combination of different materials and additives in an effective manner. In essence, the methodology which was generated in that research gives "black and white" answers to end-of-life questions which cover a broad spectrum.

In a related area, researchers at Carnegie Mellon developed a methodology for selecting materials while taking into account their environmental impacts [7]. In contrast to the methodology developed during this research, that work focused on the entire life cycle and took a more holistic view of the material selection process and its resulting environmental impact. The research of this thesis is focused specifically on the void of information about end-of-life destination choices, and how the combination of materials and additives affect those choices.

Concurrently, much research has been conducted to develop systems to determine product disassembly sequences based on both environmental and economic impact [5, 7-15]. All of those systems incorporate the selection of end-of-life destinations and their environmental impacts to some degree, but in most cases leave the end-user to select which to use without knowing which is preferred in a given situation. The system generated through this research is designed to work together with those systems to give the user the information they need to make educated end-of-life choices. It is not meant to accomplish the purposes for which those systems are designed (determination of disassembly sequences). The end-of-life classification system is meant to support those systems by providing their users with a recommended end-of-life destination. From that information, the users can decide which materials they wish to leave together or to separate for optimum disposal. The necessary modifications to the product design or disassembly sequence to incorporate those changes will be determined by one of the disassembly sequence tools referenced above.

There have also been numerous studies conducted to investigate end-use markets for plastics [16-20]. Some have been focused on specific applications, while others have tried to provide an overall view of the current status of plastics recycling. Through this research, the potential for using recycled plastics in medium to high-grade applications was investigated, as well as the current status of plastics recycling technology. The research uncovers some of the pitfalls with the current method to promote the use of recycled plastics, and offers some suggestions of future strategies which would be more effective than those currently used.

1.3 Research Procedure and Objectives

In the development of the end-of-life classification system, the first task was to create the structure of the classification system. The system was designed to provide the level of preference for each end-of-life destination, for any type of material. For combinations of materials and additives, the system needs to merge the specific preference information, using compatibility factors, into a combined level of preference for the material blend. The system also needs to be flexible so that information can be added or modified in the future, as reprocessing and disposal alternatives advance.

The next major task was to acquire information on the possible end-of life destinations for various materials and their level of preference (ranking). Included in this information are the effects that the combinations of different materials and additives have on each other regarding those possible destinations. This information was gathered through the contact of facilities involved with material reprocessing and disposal, and also through a literature survey.

The final task in the development of the classification system was to apply it to various case studies. This would demonstrate the workings of the system and verify its potential effectiveness in disposal optimization.

To investigate the potential end-use markets for recycled resins, case studies were conducted at manufacturing companies which use plastics in their products. The situation at each company was evaluated through the assessment of the material, process, and product requirements of their existing manufacturing processes. Where potential for using recycled resins existed, sourcing substitute resins and conducting test trials on the material was pursued. Recycled resin reclaimers and reprocessors were also contacted for information surrounding the issues of recycled resin use.

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Chapter Two: End-of-Life Classification System

2.1 Introduction

The purpose of the classification system is to identify the preferred end-of-life disposal methods for assembly components of products based on their material content. By using this type of system, a recommendation can be provided on which materials should be separated from each other, or combined, for optimum reprocessing or disposal. Ultimately, it can assist the selection of part materials during initial product design by allowing the up-front consideration of the product's future disposal.

During the selection of a disposal method, the emphasis is generally placed on choosing the method with the lowest cost, and less emphasis is placed on the environmental consequences. As those environmental consequences become more of a concern, they will have more of an influence on that decision. Even so, the selection of an end-of-life disposal option will still be determined by economics, whether through the direct cost of the disposal method or through imposed penalties and tariffs for using less environmentally conscious methods. It is through this fundamental idea that the end-of-life classification system was designed.

2.2 Structure and Procedure of Classification System

The end-of-life classification system was designed to encompass all possible end-of-life destinations and common material combinations. The system was also designed to be as simple as possible. In addition, there are other qualities that a classification system should have in order to operate successfully, in the present as well as in the future [1]:

Robustness - The system should be capable of managing a large amount of data and provide the desired results.

Expandability - It is very difficult to define everything that a system must be capable of handling during some indefinite future time period. The ease of expanding the system to account for future changes is very important.

Automation - Most established classification systems are implemented using a computer. When developing a potential system, it should be determined how well the created system can be automated.

Efficiency - The system should not have excessive information, or account for possibilities which will never occur.

Simplicity - Ease of use is important. It is necessary for user acceptance, training considerations, and cost of use.

2.2.1 Structure

Once these objectives were outlined, the structure of the classification system was developed. A few different formats were considered, ranging from matrices to logic trees and combinations of both. In the end a matrix system structure, which was viewed to be the most straight forward format, was chosen. A simplified version of the resulting Main Table of the classification system structure is shown as Table 2.1.

Table 2.1: Simplified Main Table

			Recycle			Reprocess				Landfill	
Primary Material	Second Material	Coatings, Additives, Fillers	recycled, without need for material segregation	recycled, segregation of co-mingled materials or special processing required	reground and used as part fillers	reprocessed chemically or thermally to recover basic material constituents	incineration used to recover heat energy and material	incineration used to recover heat energyand material, with toxic controls	unique process used for hazardous waste treatment	landfill / normal waste	landfill / hazardous waste

The format of the Main Table lists the possible end-of-life destinations (based solely on material content) in columns, from left to right in order of environmental preference. Down the left side of the table are where materials and additives for each part, or group of parts, would be input.

When the materials and additives have been specified and input into the Main Table, information from their respective Materials, Additives, and Group Compatibility Tables (see Appendix A, End-of-Life Classification System) would be input into the Main Table accordingly. The format of Materials, Additives, and Group Compatibility Tables is the same as the format of the Main Table, with the end-of-life destinations listed across the top. The Materials and Additives Tables are each divided into three different tables, one for each of the three main material groups: Plastics, Metals, and Miscellaneous. Where applicable, the system structure also includes Material

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Compatibility Tables (Appendix A) which are in a material versus material matrix format (as opposed to material versus end-of-life destination).

2.2.2 Procedure

The structure of the classification system was designed to be as simple as possible. Simplicity was also required from the procedure designed to drive it. The way the system procedure works is as follows (for all classification system tables, see Appendix A):

1. The first input location in the Main Table is for the primary material of the part, or group of parts. Once the primary material has been selected, the rankings (level of preference) for each end-of-life category are input into the Main Table from the material's corresponding row in the Materials Table. Those rankings are scaled from 0.0 to 100.0 (100.0 being the best).

2. The next input locations in the Main Table are for secondary materials. When any secondary materials have been chosen, their end-of-life effect factors are multiplied against the primary material rankings already in the Main Table, in each respective end-of-life category. Effect factors are scaled from 0.0 to 1.0 (1.0 being the best). Depending on which material group each secondary material is from, those effect factors either come from the Group Compatibility Table (when the combined

materials are from different material groups; step 2-A) or the Material Compatibility Tables (when the combined materials are from the same material group; step 2-B).

2-A. When the Group Compatibility Table is used, the first step is to select the row which refers to the type of material combination; Metals / Plastic, Plastics / Miscellaneous etc. The first material group in the name is the primary material. Then the effect factors from the appropriate row are multiplied against the primary material rankings in the Main Table in each respective end-of-life category. If there is more than one type of material combination present, only use the effect factors from the predominant combination.

2-B. The Material Compatibility Tables are in a matrix format. The materials to be combined are listed across the sides in rows and columns. First, the primary and secondary materials are selected and the corresponding effect factor for the combination is found in the matrix. Then, the effect factor is multiplied against the primary material rankings in the Main Table in the recycling end-of-life destinations. This is repeated for each additional material present from the same material group. Note that the Material Compatibility Tables only apply to the first end-of-life destination concerning recycling. It is assumed that a combination of materials from the same group will not affect any of the other end-of-life destinations (effect factor = 1.0).

3. The last input locations in the Main Table are for additives, coatings, and fillers which are present in the primary material. Depending for which material group the

additives are used, effect factors are multiplied against the primary material rankings in each respective end-of-life category. Those factors come from the Additives Table for the material group in which the primary material belongs. Effect factors are scaled from 0.0 to 1.0 (1.0 being the best).

4. The final step in the system would be to analyze the resulting data and determine which end-of-life destination is preferred for the material, or combination of materials. There are a few different proposed methods for this which will be discussed in section 2.7 (Recommending an End-of-Life Destination).

2.3 Parameters of the Classification System: Limitations and Assumptions

The focus of this research was to develop a classification system to identify the preferred end-of-life destinations for assembly components based on their material content. The materials considered in this system are those which are predominantly used in durable goods. Since it is material content which drives the classification system, there are inherent boundaries to this system. The system cannot determine the preferred end-of-life destination, or provide a ranking, based on:

- the geometry or size of the parts
- the working condition of the parts
- how the parts are assembled and the assembly order
- whether bulk recycling can be employed

Keeping in mind the boundaries associated with a material content driven classification system, there are also some assumptions which need to be made in order to simplify the system and make it efficient to use:

<u>Basing a material classification system on the selection of a primary material is valid.</u>

To achieve the simplest material classification system, it is easiest to design the system so that it based off a primary material. The system documents the end-of-life destination preference for the primary material, then indicates the effects on those preferences from all the other materials and additives present. The assumption is that there will always be a primary material in a part, or group of parts, which accounts for most of the material or is of primary interest.

In the cases where there are two materials which could both be considered the primary material, the mechanics of the system should take care of this problem. When the materials are from the same material group, they have basically the same material properties which govern what end-of-life destinations are possible and their level of preference. Therefore there will be little significant difference in the end-of-life rankings if either material is chosen. It should also be noted that the Material Compatibility Tables are not dependent on a primary / secondary material relationship, so which material is the primary one is not an issue with these compatibility factors.

If the two materials belong to two different material groups, the problem will also be minimal. This is due to the material group assumption described in more detail below.

Materials of different material groups have different material properties which govern what end-of-life destinations are possible and their level of preference. These relative differences translate themselves into the effect factors of the Group Compatibility Table. The effect factors, for the most part, are independent of which material is the primary material. In the cases where this is not so, the difference between effect factors is usually small and limited to only one or two end-of-life destinations. Therefore the difference has been considered negligible.

<u>Amount of materials and additives combined with primary material are significant.</u>

Indicating the combination of secondary materials and additives with the primary material assumes that their presence has a significant impact on the primary material's possible end-of-life destinations. If the amount of the secondary material or additives combined with the primary material is known to be too small to have any impact, then they should not be included in the analysis. The effect factors generated to indicate the impacts on the primary material assume that the amount of secondary material or additive present is enough to significantly affect the end-of-life rankings.

<u>Users will not select material and additive combinations which are not possible.</u>

To keep the classification system simple, excessive measures have not been added to prevent the selection of impractical or impossible material and additive combinations. It must be assumed that the user of the system will be knowledgeable enough not to input any impractical material combinations into the system. The user will most likely know the material content of the product they are analyzing, or can come up with a rational estimation. It is reasonable to assume that they will not select an additive or material which cannot be used with the primary material or that they are unsure about. Therefore little need exists to identify additives and coatings which do not apply to specific materials.

When combining materials from the different material groups, their effect on each other's end-of-life preferences are the same for all of materials in their groups.

Due to the significant differences in the material properties between the different material groups, the effects that each group has on the other's end-of-life destinations is also significant. The significant differences in material properties make their affects on the other material's end-of-life ranking prominent. This allows for the assumption that the materials in each group have the same overall effects on the other group's end-of-life destination rankings.

All additives for a material group affect the end-of-life rankings of all the materials in that group the same way.

Using the same logic as was applied for combinations of materials from different groups, the assumption of a holistic affect on each material's end-of-life rankings was made for additives. Additives, coatings, and fillers have obvious impacts on the properties of the primary material, which subsequently affects the material's end-of-life destination rankings. It has been assumed that the additive types will have the same impact across all of the materials in their respective group.

“Two wrongs don’t make a right.”

Another assumption which is made is that if two additives in a material each have a negative impact on the material’s end-of-life destination ranking, then their combined impact will also be negative. Theoretically, it could be possible that a combination of additives may interact with one another and actually nullify their negative impacts. However, that possibility has been assumed to be negligible.

Quantities of materials are assumed to be large enough for economical use.

The effect rankings (which are discussed in section 2.5, End-of-Life Destination Ranking Methodology) are based on the average amount of material which allows all end-of-life destinations to be viable options. It should be noted that when the user considers which end-of-life destination to employ, the economics of quantity should be taken into account.

Quality of materials are assumed to be average.

The quality of material, which is of concern in the recycling end-of-life destinations, is assumed to be “average”. This refers to the quality degradation and dilution of properties which is typically expected from the cyclical processing over the material's life. It is also assumed that the material is in an ideal condition (e.g. minimal contaminants and minimal property degradation during the product's use).

<u>Up to user to decide if parts can be reused or remanufactured.</u>

The most environmentally, and economically, preferred end-of-life destinations are either the reuse or remanufacture of parts and subassemblies. As a material driven end-of-life classification system cannot determine if those two disposal options are possible, it is up to the user to determine the possibility of reuse or remanufacture. These two end-of-life destinations should always be considered.

<u>Up to the user to know what end-of-life destinations are available to them.</u>

The economically based rankings assume an average quantity of the material which will provide economic motivation to consider all possible end-of-life destinations. In the end, however, the user must determine which end-of-life destinations are available to them, and which are economical to pursue. The information provided in the tables of the system are meant as a guide for estimating which end-of-life destination will be the most economically desirable, relative to its environmental desirability. It also must be remembered that all end-of-life destinations may not be available in every geographic location.

2.4 Description of End-of-Life Destinations

The groundwork for defining the end-of-life destinations was established during previous work [2]. However, many of those end-of-life destinations were material specific and needed to be redefined and consolidated so that the destinations could be universal for any given material. It must also be remembered that this classification system is driven solely by material type. Therefore, end-of-life destinations which require the supplementary evaluation of other criteria are not included. The resulting categories of end-of-life destinations are as follows:

Recycle

- Recycled, without need for material segregation
- Recycled, segregation of co-mingled materials or special processing required
- Reground and used as part fillers

Reprocess

- Reprocessed chemically or thermally to recover basic material constituents
- Incineration used to recover heat energy and material
- Incineration used to recover heat energy and material, with toxic controls
- Unique process used for hazardous waste treatment

Landfill

- Landfill / normal waste
- Landfill / hazardous waste

A more in-depth explanation of what each of these end-of-life destination categories encompass is provided below:

Recycle - recycled, without need for material segregation

The regrinding and reuse of the material as feedstock for new components. In this situation, the mixture of material used is not segregated and is processed “as-is”.

Recycle - recycled, segregation of co-mingled materials or special processing required

The regrinding and reuse of the material as feedstock for new components. In this situation, the mixture of material used is segregated, pre-treated, and each material is processed or disposed of independently.

Recycle - reground and used as part fillers

Material is reground into particles and used as partial fillers in substitution of virgin materials or to create a composite material.

Reprocess - reprocessed chemically or thermally to recover basic material constituents

This category covers many alternate methods of recycling materials to recover the basic material constituents used to produce them. This category encompasses such processes for plastics as glycolysis, hydrolysis, and pyrolysis, as well as recovery methods for other material types.

[redacted]cess - incineration used to recover heat energy and material

Controlled process that uses combustion to convert waste into thermal energy which is then typically used to generate electrical energy. This process also reduces the size of the material to enter the waste stream.

[redacted]rocess - incineration used to recover heat energy and material, with toxic controls

The same as normal incineration, except certain materials may contain undesirable compounds. Secondary treatments and atmospheric controls such as afterburning, scrubbing or filtration is required to lower concentrations of toxins to acceptable levels prior to atmospheric release. The solid and liquid effluents from secondary treatment processes will occasionally require further treatment prior to ultimate disposal.

Reprocess - unique process used for hazardous waste treatment

These are typically proprietary processes for hazardous waste treatment developed by recycling companies. Some examples are the treatment processes used during the reclaim of CRT's in televisions and CFC's in refrigerators.

Landfill / normal waste

Material is taken to a landfill where it is buried.

Landfill / hazardous waste

Same as Landfill, except the materials to be disposed of are classified as hazardous when placed in landfills. Therefore, special disposal considerations are required.

There are other possible end-of-life destinations for products, however they cannot be determined simply based on the material used in them. The validity of those destinations can only be determined by the user of the system. These other end-of-life destinations are listed below:

Reuse

Materials recovered have the potential to be reused, as is, directly in other assemblies or into specific manufacturing processes.

Remanufacture

Parts reclaimed from retired products are remanufactured and reused for secondary markets. Remanufacturing costs are product dependent.

Special note: the recycling end-of-life destinations for standard assemblies (with D codes in the Miscellaneous Materials Table), are actually considered "reuse" as defined above.

2.5 End-of-Life Destination Ranking Methodology

Much thought was given to how to rank each material for each end-of-life destination beyond environmental considerations alone. It was determined that there were three main factors which should be used to select the best end-of-life destination for a given material: environmental impact, technological practicality, and economic considerations. After further thought, it was decided that the main driver was economics. The level of technological practicality can be measured by economic means. The less practical the technology is, the more it will cost to use it, and visa-versa. Environmental impact can also be measured economically, through the imposition of tariffs and elevated disposal costs due to decreasing landfill space and environmental harm.

Realistically, manufacturers will base their disposal decision primarily on economic concerns. Their ultimate goal as a manufacturer is to make money and they will want the economic burden of waste disposal to be minimal. With this in mind, the preference rankings generated through this research are based on the economics of End-of-Life Disposal Processes (which incorporates the economics of environmental impact) and End-Use Market Demand. The total ranking would be out of 100 points, with half the points devoted to each of the two economic drivers.

Once it was determined that the ranking should be based on a relative economic factor, how to generate that ranking needed to be determined. First, information about the end-of-life disposal of various materials was researched in order to have an understanding of the preferred material disposal practices. This information was obtained through a literature survey and through the contact of facilities directly involved with material reprocessing and disposal.

Information was also researched to uncover the impact of combining materials and additives on end-of-life disposal. The two primary areas of impact that were investigated were effects on reprocessing (cost) and effects on end-use market demand. In this system, the impact that each item has on a material's ranking is defined by an effect factor (from 0.0 to 1.0) which is multiplied against the end-of-life ranking. The total points for the effect factor, like that of the end-of-life ranking, are proportioned evenly between the two economic drivers.

During the search for information on the end-of-life impact of additives, a limited amount of information was available due to a lack of previous research, studies, or written documentation in that area. Therefore, a wide range of facilities involved with material reprocessing and disposal were contacted to supplement that information. Because of the lack of previous research, many of the rankings and factors of the system would have to be based on the experiences of those facilities; an approach based on expert opinion rather than one based on hard data. The various sources of information that were used to determine the end-of-life rankings and effect factors are listed in the Bibliography of this report.

To continue to keep the system simple, a few assumptions about the effect rankings and factors had to be made. Those assumptions were previously discussed in section 2.3 (Parameters of the Classification System: Limitations and Assumptions).

With the necessary assumptions outlined, the rankings and effect factors for the classification system tables could be determined.

This section focuses on the issues surrounding end-of-life disposal that were translated into the rankings and effect factors. As the actual table values themselves are relative and somewhat arbitrary, the emphasis will be to provide a general understanding of the issues behind those values, rather than to scrutinize the values themselves.

2.5.1 General Rankings and Effect Factors for End-of-Life Destinations

After researching the recycling, reprocessing, and disposal methods of different materials, it was found that there were end-of-life issues common to all materials:

<u>Recycling:</u>

For effective material recycling, the "purer" the material (the closer its properties are to virgin material) the more end-use market demand it has. Different qualities of material can be blended without any processing problems. However, the less "pure" the material is, the lower the desire for its use in end-use markets. To increase the demand for the material, the market cost will have to be significantly lower to compensate. Therefore, it is best to keep the types, properties, alloys, etc., of a certain material consistent within a given product, as well as consistent with materials that are commonly recycled as a whole.

When developing the end-of-life rankings for recycling, there were a couple issues to consider. One issue was the costs due to recycling processes and technology. For almost all of the materials investigated, the costs of processing and technology were typically the same across each material group. However, when the segregation of co-mingled materials or other processes are required before recycling, then the rankings decrease according to the difficulty of sorting, cleaning, and preparing the material.

The main issues which determined the level of recycling preference were the availability of end use market demand for reuse of the material, the amount of material reclaimers who collect and reprocess the material, and the quantity of the materials which needed to be collected in order to make recycling economical. If the material is commonly recycled, then the quantities are of little concern. The materials that are most commonly recycled were given a higher ranking due to their better logistics of collection and market resale. However, if it is not commonly recycled, then the quantity of the material must be large enough to justify doing so.

Regrinding the material for use as a part filler can almost always be considered a disposal option. In ranking material for this possibility, the main concept was that the material would be an inert filler material. If there was a possibility of reacting with any primary materials in which it would be a part, or make the material unsafe, then a lower ranking was given.

Reprocessing:

The first end-of-life destination which falls under this category is the reprocessing of materials, chemically or thermally, to recover the basic material constituents. Since the processes involved can usually account for any material combinations, the impact of those material combinations was not of much concern. The primary factor for this destination is the actual cost of the reprocessing technologies. These technologies are usually more complex than basic recycling processes, which is why a higher front end cost was assumed. Since the goal of the reprocessing is to recover the basic material constituents, however, the materials recovered will have a higher end-use market demand because their properties will be close to those of virgin materials.

The rankings for incineration were developed based of the potential amount of energy release from the material to be incinerated. A lower overall ranking was given to incineration because of the limited amount of waste-to-energy incinerators in operation. If toxic controls were required due to toxic emissions given off during combustion, then the cost of the those controls causes the overall ranking to decrease. The possibility of incineration will have to be investigated by the user of the system to verify its availability in their geographic region.

For unique processes for hazardous waste, it was assumed that a fixed fee would be imposed due to the special considerations required. Disposal of any material combined with one which requires unique processing will have to go through that processing as well.

<u>Landfilling:</u>

There are virtually no limitations on which materials can be disposed of in a landfill, beyond hazardous materials. Since landfilling is an equal possibility for all material combinations, a general ranking was given based on landfill tipping fees. Metals were given a slightly lower preference based on economics. This is because of a higher cost of disposal due to a higher material density. In the case of hazardous landfills, it was assumed that a flat fee would be imposed due to the special considerations required. Disposal of any material combined with one that requires hazardous landfilling will also be penalized.

2.5.2 Rankings and Effect Factors for Plastics

Information was gathered about the reprocessing and disposal practices for plastics. From the available information, rankings and effect factors were determined for their end-of-life destinations. In addition to the issues discussed in the previous section, there are a few end-of-life issues specific to plastics.

To determine the end-of-life impacts of recycling different types of plastics together, data was compiled and merged from compatibility tables from numerous sources [4,5,6] into the effect factors of the Plastics Compatibility Table. The effect factors are based on the premise that the amount of each material is inconsequential to the compatibility between them. In the cases where this was not true, the worst compatibility factor which could result from the combination selected.

General information was also gathered to investigate how coatings, additives, and fillers effect the reprocessing and disposal of plastics. For the most part, additives simply alter a few of the material properties of the plastic to increase performance. This creates the material quality issues cited in the previous section (new material properties compared to those of virgin materials) and lowers the material's ranking based on end-use markets. In some cases, additives will affect the properties of the plastics in a way which limits the technical possibilities of certain end-of-life destinations.

Chemical blowing agents, for instance, affect the current methods used for plastics sortation based on material densities. The blowing agents are used to create structural foam plastic, and the "air-pockets" added to the material alters its true density. This makes the material more difficult to sort when co-mingled with other plastics.

Metal coatings, just as with metals inserts and parts, are incompatible with plastic in direct recycling processes. However, there are current techniques to remove metal coatings, or the plastic can sometimes be incinerated for energy, leaving behind a metal residue. The use of paints is another problem and affects the end-of-life preferences of plastic in the same ways that metal coatings do. The exception to this is that they are more acceptable in incineration, although toxic controls may be required.

For incineration, the plastics with the highest waste-to-energy potential were given the higher level of preference due to the greater amount of reclaimed energy. It was assumed that the nature of flame retardants and heat stabilizers would reduce the ease of incineration, which accounts for the lower rankings.

For a more detailed description about the issues surrounding the processing and reuse of reclaimed plastic, see Chapter Three: Potential Use of Recycled Plastics in Manufacturing Processes.

2.5.3 Rankings and Effect Factors for Metals

For the information concerning the reprocessing of metals, first hand information was gathered from the collectors and reprocessors of scrap metal. Due to the material characteristics of metals, they do not have incompatibility and contamination problems to the same degree that plastics have. For the most part, all sorts of alloys and blends of metals can be reclaimed, reprocessed, and resold. There is usually a market for different alloys and mixes of them, but as stated previously in section 2.5.1, the purer the material the more resale outlets will be available. As the technology for recycling metals is well established, their recycling rankings were based primarily on their end-use market value.

For the most part, foreign contaminates are not a problem for metals reprocessing. Most contaminates will burn off during the remelting of the metal. Therefore, the effect that they have on the end-of-life ranking is minimal. There can be some problems with metal coatings of "undesired" metals when reprocessing. Some reclaimers cited the examples of plating with tin, lead, cadmium, and the specific example of a plumbing brass with a chrome plating. They stated that galvanizing steel or anodizing aluminum does not create a problem. Note also that for metals, incineration is not considered a valid end-of-life destination.

As there are various possibilities for the combining of metals, creating a straight forward recycling compatibility chart (as done for plastics) could not be done effectively. Metals compatibility should be considered under the general statements that different classes of metals (steel, aluminum, copper) should be kept separate during processing, while combining different alloys of the same metal are less of a concern. The closer the material properties are to one another, the better, however there will always exceptions.

2.6 Example of System Procedure

Now that the necessary background information about the developed classification system has been laid out, an example of the system procedure can be demonstrated effectively. Below is a step-by-step example of how the system calculation works (refer to section 2.2, Structure and Procedure of Classification System for the written description of the system structure and procedure). To automate the calculations, codes were given to each material and additive, which are indicated to the left of them in the Material and Additive Tables (Appendix A). As there are no secondary materials present in this example, their columns have been omitted from the Main Table shown in Table 2.2.

Table 2.2: System Example

					Recycle			Reprocess				Landfill	
	Primary Material	Coatings, Additives, Fillers			recycled, without need for material segregation	recycled, segregation of co-mingled materials or special processing required	reground and used as part fillers	reprocessed chemically or thermally to recover basic material constituents	incineration used to recover heat energy and material	incineration used to recover heat energyand material, with toxic controls	unique process used for hazardous waste treatment	landfill / normal waste	landfill / hazardous waste
STEP #1	P8				70.0	50.0	60.0	75.0	75.0	60.0	10.0	85.0	40.0
STEP #2	P8	AP4			49.0	25.0	48.0	52.5	63.8	51.0	10.0	85.0	40.0
STEP #3	P8	AP4	AP19		14.7	15.0	36.0	47.3	47.8	38.3	10.0	85.0	40.0
STEP #4	P8	AP4	AP19	AP22	14.0	14.3	32.4	42.5	47.8	38.3	10.0	85.0	40.0

Note: P8 = PC (polycarbonate) AP19 = Metal Coatings AP4 = Chemical Blowing Agents
AP22 = Lables, compatable plastic

STEP #1. The code for the primary material is input into the Main Table. The values (rankings) for each end-of-life destination are input into the Main Table from material's corresponding row in the Materials Table.

STEP #2. The code for the first additive which is present is input into the Main Table. Then the corresponding effect factors from the Additives Table are multiplied against the rankings in the Main Table in each respective end-of-life category.

STEP #3. Step #2 is repeated for the second additive present with the primary material.

STEP #4. Step #2 is repeated for the third additive present with the primary material.

The bottom line of the system example (Table 2.2) gives the final end-of-life preferences. It can be seen that the end-of-life destination with the highest preference (85.0) is Landfill / Normal Waste. However, if the user of this system wanted to consider using a disposal option other than landfilling, the results suggest that they look into either incineration or reprocessing as they have the next highest levels of preference.

2.7 Recommending an End-of-Life Destination

The final step which remains of the system procedure is the interpretation of the results. The strength of the proposed end-of-life classification system is that it indicates which end-of-life destinations are possible by providing a level of preference for each. Therefore, the user should look at the results and see which end-of-life destinations have the highest levels of preference. From that information, the user should then investigate the availability and economics of those destinations in their geographic region to select the most appropriate disposal option for their needs (see section 2.3, Parameters of the Classification System: Limitations and Assumptions). Then they should experiment with different combinations of materials and additives to optimize the products disposal.

To have the classification system recommend a specific end-of-life destination will take away the strengths of the system's "analog" preferences and "digitize" them into one preferred destination. This "digitizing", or providing "black and white" answers, was one of the shortcomings mentioned of the previous classification system [2]. Also, the rankings themselves are relative and can only approximate the end-of-life preferences. The user should consider all end-of-life options that are in the same range of preference. However, if a default end-of-life recommendation is still desired, despite the aforementioned warning, there are a few suggested methods for doing so. The choice of which method to use depends on the interests and requirements of the user.

Economic Strategy

One strategy for generating an end-of-life recommendation would be one driven mostly by economic considerations; the end-of-life preferences themselves. The default end-of-life destination would be the destination with the highest level of preference. If two or more destinations have the same value, then the most environmentally friendly option would be selected (the destination closest to the left; end-of-life destinations are listed in the tables from left to right in order of environmental preference).

Environmental Strategy

The other recommended strategy would focus more on environmental impact. It could designate the first end-of-life destination (from left to right) with a level of preference equal to, or greater than, some value (e.g., 60) as the preferred destination. Another possible method to do this is to neglect the end-of-life destination of landfill and then the highest level of preference of the remaining destinations would be the recommended one. This is the environmental method which will be used during the analysis of the case studies.

2.8 Case Studies

Case studies were conducted to help demonstrate the workings of the system and verify its potential effectiveness in evaluating end-of-life disposal options. Two case studies were conducted; 1) IBM PS/2 Personal Computer and a 2) 1995 GM Truck Instrument Panel. These case studies were initially investigated during concurrent Design for Disassembly and Environment research [3]. Since the end-of-life classification system is meant to work concurrently with Design for Environment (DFE) analysis methods, it was logical to utilize those case studies. The parts and materials of the case studies were grouped together as indicated in the previous DFE studies. The part names shown in italics are those for which the user in the original DFE analysis has chosen reuse or remanufacture as the end-of-life destinations.

2.8.1 Case Study of a Computer

The first case study was of an IBM PS/2 Personal Computer (this only refers to the central processing unit; not the monitor, keyboard, etc.). The resulting Main Table for the case study analysis is shown in Appendix A. The results were analyzed using both of the strategies proposed for recommending an end-of-life destination described in the previous section, shown in Figures 2.1, 2.2, and 2.3. In the cases where two end-of-life destinations had the same level of preference, a shared category was created with both their names, divided by a slash.

Figure 2.1: IBM PS/2 End-of-Life Destinations by Economic Strategy (percentage by weight)

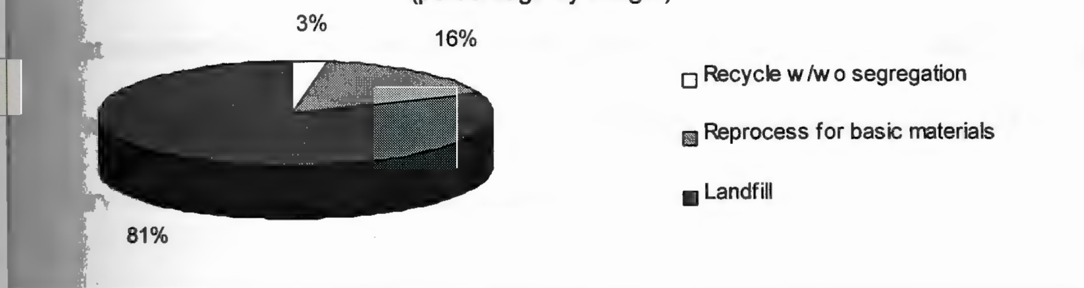


Figure 2.2: IBM PS/2 End-of-Life Destinations by Environmental Strategy (No landfilling; percentage by weight)

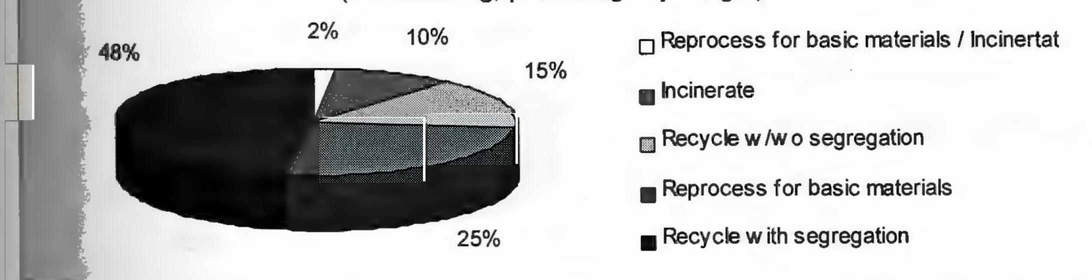
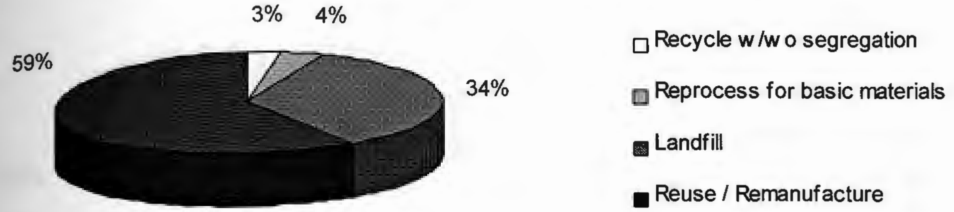


Figure 2.3: IBM PS/2 End-of-Life Destinations by Economic Strategy and Potential for Reuse / Remanufacture (percentage by weight)



2.8.2 Case Study of a Dashboard

The second case study was of a 1995 GM Truck Instrument Panel. The resulting Main Table for the case study analysis is shown in Appendix A. The results were analyzed using both of the strategies proposed for recommending an end-of-life destination described in the previous section, shown in Figures 2.4, 2.5, and 2.6. In the cases where two end-of-life destinations had the same level of preference, a shared category was created with both their names, divided by a slash.

Figure 2.4: GM Truck Instrument Panel End-of-Life Destinations by Economic Strategy (percentage by weight)

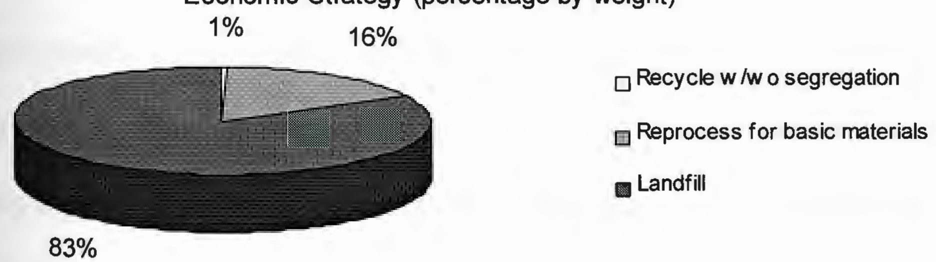


Figure 2.5: GM Truck Instrument Panel End-of-Life Destinations by Environmental Strategy (No landfilling; percentage by weight)

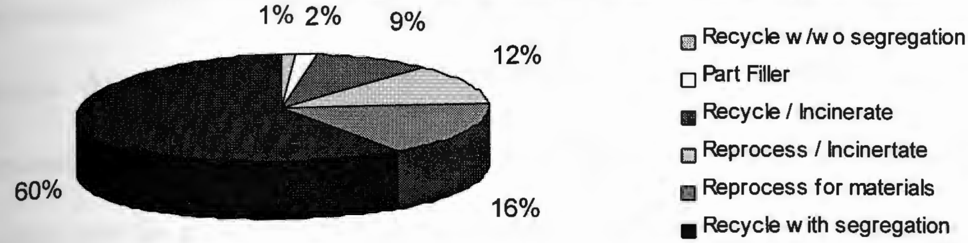
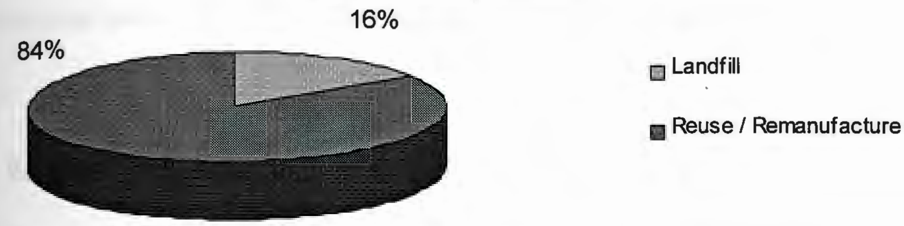


Figure 2.6: GM Truck Instrument Panel End-of-Life Destinations by Economic Strategy and Potential for Reuse / Remanufacture (percentage by weight)



2.8.3 Results of Case Studies

By looking at the charts in Figures 2.1 and 2.4, it can be seen that based on the economic strategy for recommending end-of-life disposal, these products are currently designed so that landfill disposal is the most economical option. The current disposal practices for durable goods verifies this reality. More than 80% of the components by weight in each assembly are destined for the landfill based on the selection of materials of which they are composed. If landfilling is not considered an option, then the resulting end-of-life destinations that are recommended are more diversified (Figures 2.2 and 2.5). Based on the environmental strategy, more than 60% of the components by weight are recommended to be recycled in each case study.

When considering the possibilities of reuse or remanufacture, determined by the user, combined with the economic strategy (Figures 2.3 and 2.6) the situation appears to improve. Approximately 60% and 83% of the total weight of the IBM PS/2 and GM Instrument panel respectively can either be reused or remanufactured. It should be noted, however, that the portion of parts designated to be reused or remanufactured by the user only have the "potential" for reuse or remanufacture. If those parts are in a degraded condition where reuse or remanufacture is not an option, then the end-of-life disposal picture reverts back to the original assessment of Figures 2.1 and 2.4.

2.9 End-of-Life Guidelines

During the investigation to determine the end-of-life rankings and effect factors, guidelines emerged for designing products for end-of-life. These guidelines also manifested themselves while evaluating the results of the case studies. Recognizing these basic guidelines during the onset of product design will help designers to optimize their disposal decisions. Many of these guidelines have already been discussed in section 2.5.1 (End-of-Life Destination Ranking Methodology) and are summarized in the following list:

1. The closer the material properties are to virgin material, the more end-use market demand exists for recycling. Therefore, it is ideal for the parts of an assembly to be of the same, standard material and with minimal additives incorporated into them.
2. Parts made from the same material should be grouped together, and the different types of materials in an assembly should be limited. The larger the amount of different

materials in a part or group of parts, the larger the preference becomes for landfilling over other end-of-life destinations.

3. The quantity of material is important when considering recycling. Part materials that are present in small quantities should be the same as those that are typically collected. Part materials that a present in large quantities can possibly create their own demand, thus reducing the need for the pre-existence of a large, collected supply of material.
4. In general, it is possible to recycle all basic thermoplastics and metals. However, end-use demand and marketable quantities are what will determine which materials are economical to recycle.

2.10 Conclusion

This end-of-life classification system is designed for the salvaging, reprocessing, and disposal of materials. The largest economic "gains" in disposal, however, are in the two end-of-life destinations the system is not designed to recommend; reuse and remanufacture. After part reuse and remanufacture have been considered, the end-of-life classification system helps to determine how to dispose of the "rest fraction" of material that remains. The developed system accomplishes this effectively, by offering disposal preferences based on the materials used, and show how combinations of those materials impact end-of-life disposal. The future use of this classification system will depend on the desire of product manufacturers and dismantlers to optimize product disposal. These desires will be created by economic pressures, environmental pressures, or both.

Chapter 2 References

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[4] G.E. Plastics, Design for Recycling, DFR ENG. 6M/0392, no date.

[5] Dow Plastics, Designing a Green Guide, no date.

[6] TNO Product Center, "Recycling Compatibility of Thermoplastic Polymers", Design for Environment, May 1996.

Chapter Three: Potential Use of Recycled Plastics in Manufacturing Processes

3.1 Introduction

The purpose of this project was to investigate potential uses for recycled plastics within various manufacturing processes at companies located throughout Rhode Island. The potential for using recycled resins was evaluated at each company through the assessment of the material, process, and product requirements for their existing manufacturing processes. Where potential for using recycled resins existed, sourcing substitute resins and conducting test trials on the material was pursued. The manufacturing processes targeted were injection molding, extrusion, film extrusion, blow molding, and the manufacture of patterns for investment casting.

This project also involved the development of acceptance test procedures, with input from the companies involved, to be used during the selection of substitute resins. These procedures focus on assessing the ability of the substitute resin to meet the material, process, and product requirements. The procedures were designed to provide a general, all encompassing format for selecting resins within the range of targeted manufacturing processes. The format allows companies to tailor the procedures to their individual manufacturing requirements.

The importance of this project is to promote the use of post-consumer and post-industrial resins in manufacturing, thus increasing the demand and strengthening the markets for recycled resins. The end goal is to uncover the major issues surrounding the use of recycled plastics within the investigated applications. Suggested strategies for promoting the use of recycled resins in the future are also discussed.

The major objectives of this study were to:

- Investigate the potential for using recycled plastic in various applications and the associated manufacturing processes.
- Develop testing procedures to assess the potential for using recycled plastic in different manufacturing processes.
- Conduct testing of post-consumer plastics for use at local companies where potential exists.

Secondary objectives include:

- Reduce the amount of material disposed by finding alternative uses in industry for recycled resins.
- Encourage the development of markets for recycled plastics by providing information and technical assistance on their use in various processes and products.

3.1.1 Background

The disposal of solid waste is an environmental problem of increasing burden. Due to the growing concerns of decreasing landfill space, waste toxicity, and lost natural resources due to incineration and landfilling, better alternatives to solid waste disposal need to be considered. One alternative has been to redirect materials from the waste stream and collect it through recycling programs. However, for material collection to be an effective alternative, end-use markets must exist which can use the material.

The collection, recycling, and reuse of post-consumer metals, glass, and paper have become relatively common activities. End-use markets are more readily available for those three materials and in many cases are cost competitive. Their potential to be reused is somewhat taken for granted due to the relative ease of material segregation and processing. Their ease of recycling can be attributed to the limited types of the materials, minimal specification requirements for new products, limited contamination problems, and minimal degradation of the material quality after reprocessing. This ease of recycling allows for closed-loop recycling within many applications.

Plastics, as a diverse family of polymeric materials, have historically presented a challenge in market reuse. There are many different types of plastic resins, as well as many different fillers and additives to blend into them. As a result, the amount of possible plastic formulations is unlimited. While this diversity makes plastic a versatile material, the distinct physical and chemical properties of each different formulation make plastic recycling difficult. The incompatibility that exists between many different plastics in recycling processes requires the separation of the plastics into distinct resin types, technology for which is in its infancy.

Contamination of plastics can lead to degraded quality of the end product that contains it. Contamination can be considered either a plastic with different properties or foreign debris (e.g. dirt, paper labels, glue, oil, and grease). Although foreign debris will burn off when recycling glass or metals, they become contaminants and degrade plastics during reprocessing. Depending on the manufacturing process and product application, the slightest amount of contamination can be detrimental to the process and material performance. This is the main reason that proper segregation of plastics into resin types and removing contamination debris is so important.

Plastics are classified into two major categories, thermoplastics and thermosets, and each encompasses a variety of resin types. Thermoplastics can be remelted and reprocessed repeatedly, while thermosets cannot. During final processing, thermosets go through a chemical change in addition to a phase change. This change in chemical structure is a formation of a three-dimensional cross-linked network of molecules which cannot be made to flow under pressure when heated. Therefore, only thermoplastics can be effectively recycled as feedstock material and consequently were the focus of this project. (Note: thermosets can be ground-up for use "as is" as an inert filler material, but in limited amounts).

3.1.2 Status of Plastic Recycling

Plastics are a growing contributor to the problem of solid waste disposal as they continue to replace other materials in the marketplace. Although they only account for 8% of total main-stream waste by weight, they comprise 20% by volume [1]. Volume is the important factor to consider because it determines how much landfill capacity is utilized. The reason for the high volume to weight ratio of plastics as waste is in their ability to return to their original shape after being compacted.

Another common disposal option for plastics is incineration. To many, this is the best option for plastics disposal due to the high energy reclaim from its combustion. However, incineration does not accomplish the goal of resource conservation, and is still considered controversial due to perceived health risks. These characteristic are why plastics are a serious disposal concern and are a reason why utilizing better alternatives to landfill disposal and incineration have grown in importance.

Recycled plastics are often classified as either post-consumer or post-industrial. Post-consumer plastics refer to materials recovered from consumers after it has served its intended use. Post-industrial plastics refer to the scrap produced during plastic processing that is not reused internally. This should not be confused with the in-process or in-house reuse of plastics.

In 1994, approximately 13.6%, or 1.7 billion pounds, of post-consumer plastic were recycled in the United States [2]. This was a 22.1% increase from the 1.4 billion pounds recycled in 1993. Plastic packaging accounted for most of the amount recycled

(1.25 billion pounds in 1994), most of which were plastic bottles and containers (1.1 billion pounds).

The major focus of plastics recycling has been on post-consumer packaging because of its short life span and relative ease of collection. Packaging collection has centered primarily on polyethylene terephthalate (PET) beverage bottles and high density polyethylene (HDPE) milk and water jugs. This is because they are used in large quantities, they are easily sorted from main-stream waste, and their competitive market value makes recycling them somewhat profitable [3]. PET bottles accounted for more than 547 million pounds of recycled plastic in 1994 [2]. 486 million pounds of HDPE bottles were recycled as well. Together, 1.21 billion pounds of PET and HDPE were recycled in 1994, comprising 71% of the total amount of post-consumer plastics recycled.

Many of the other thermoplastics used in consumer packaging occur in much smaller amounts than PET and HDPE, hindering the economical collection, reprocessing, and redistribution of these plastics. In addition, many of the plastics have a low market value which does not make them very cost effective to recycle. In some cases the environmental impact of recycling these materials is worse than if it had been landfilled. This is why collection and recycling of those post-consumer plastics are currently on a smaller scale. However, improvements in sorting and processing technologies are helping to close this gap.

Another potential source of post-consumer plastic to recycle is in durable goods. Almost 20 billion pounds of plastic are used each year to produce them [4]. These durable goods include such things as automobiles, appliances, computers, and electronic equipment. The engineering plastics used in these products are typically the most valuable, on a cost per pound basis. However, they are the least recovered material in durable goods. This is primarily due to the existing technical barriers involved with retrieving the plastics from the mixed material. The barriers involved with retrieving plastics from durable goods stem from:

- a broader mix of resin grades which are used.
- the presence of many different property-altering additives.
- varying density caused by structural foam.
- presence of composites and thermosets.
- large parts which impede size reduction and shape control.
- high levels of contamination.
- coatings that impede identification, sorting and melt reprocessing.

At the present, great strides are being made in development of technology to retrieve the plastic from durable goods in an efficient and cost effective manner. Once the technology to successfully retrieve the plastic is developed, another large and valued source of post-consumer plastic will be tapped.

3.2 Using Recycled Plastics

With the exception of the packaging plastics discussed previously, some problems exist in reusing post-consumer plastics, in part due to wide variations in resin grades and properties. These usually result from the limitations of the current co-mingled collection methods and separation technologies. Guarantees are limited on the level of contamination, uniform quality, or obtaining the resin in predictable quantities. These uncertainties often deter companies from using post-consumer plastics within many medium and high-grade applications. The companies' primary concern is to meet the performance, consistency, and material requirements of their customers. Meeting these frequently stringent requirements can be difficult to achieve using recycled post-consumer plastics.

Unlike post-consumer plastics, sources of post-industrial plastics are typically of a single grade of resin, resulting in a consistent quality level minimal contamination problems. Also, the available selection of the post-industrial resins supplied by reclaimers that source industry is larger than that of post-consumer packaging resins. Many resins that are not found in post-consumer packaging can be obtained from post-industrial sources. The greater selection is also due to the relatively minimal collection, sorting, and cleaning costs associated with recycling post-industrial plastics. The lower costs make it more economical to recycle those resins. The determining factors for their reuse are their market value and demand.

For a recycled plastic to be practical for use, it must be supplied in quantities sufficient for the production of the product. Also, the plastic's quality and properties should be consistent over the length of time the product will be produced. The main advantage post-industrial plastics have over most post-consumer plastics is verifiable knowledge about the source of the plastic. The plastics come from manufacturing facilities for which the quality and quantity can be determined. For post-consumer resins to compete with both virgin and post-industrial resins, a clean, well sorted, consistent supply is critical.

An adequate substitute resin could potentially be of the same resin type as the virgin material, or of an entirely different resin type. In both cases the properties of the recycled resins will differ to some degree from the virgin resins they replace. In cases where substitution of an alternative resin type is to be considered, a thorough engineering analysis will be necessary to evaluate the design parameters for the different material. Of particular concern are the processing parameters. For example, if a substitute resin has a different shrinkage rate than the original resin then the tooling, such as injection molds and extrusion dies, would have to be modified or constructed to compensate.

Although in theory thermoplastics can be remelted and reprocessed repeatedly, there are inherent limitations. When using a recycled plastic, there are many other design criteria that must be considered. Some of these criteria are property degradation, blending limitations, color, and usage regulations. The overall importance of these factors depends on the specific application in which the plastic is used.

Property degradation of thermoplastics occurs at varying levels over the time of their usage. Properties also degrade due to the heat history during remelting and reprocessing. The amount of remelting and reprocessing influences the molecular weight and material structure of the plastic, which results in property changes. The degree of those changes is dependent upon the heat history, the specific resin type, and any additives that are used. In the long term, the degradation of properties will also degrade the manufacturer's desire for using them, which itself puts a limit on the number of times the plastic will be reused.

In many current applications that use recycled plastics, a blend of both virgin and recycled plastics is employed. However, achieving a homogeneous blend is very important. This task is affected by variations between the material characteristics of recycled and virgin resins. The characteristics of primary concern are melt points, viscosity levels, densities, and the size and geometry of the pellets (or flakes). Also, since recycled resins have undergone multiple heat histories, excessive heating needs to be prevented to maintain the melt quality. Poor melt quality can lead to inadequate material properties and poor quality of the final product.

There are many manufacturers who do not want to use recycled resins, even if blended with virgin, because of the above quality issues. They feel it is not worth the risk of ruining virgin resins by blending inconsistent recycled resins into them. Also, the economic gain from blending recycled resin is minimized as the percent of recycled resin in the blend becomes smaller.

Additionally, the choice of color for recycled resins is typically very limited. The primary objective of plastic segregation is separation by resin type. Therefore many different colored plastics of the same type are collected together, reprocessed, and the result is a plastic of a typically undesirable color. In this case, the reprocessors typically color the plastic brown or black during processing. The exception to this is when the collected plastic is natural; not colored with dies or pigments. Natural color plastics are segregated out and processed separately.

There are few technological reasons why recycled thermoplastics can not be used in any of the plastics manufacturing processes. It is simply the design criteria of the final application (product) that determines the extent to which recycled resins can be used. For example, containers for food products are regulated from using recycled plastics for fear of food contamination. Therefore, to use recycled resins in food packaging it must be layered between virgin resin so that it does not contact the food. Products with stringent requirements for transparency, color, or strength may not be suitable applications for recycled resins as well.

Applications for plastic can be divided into three categories based on their product requirements. These have been termed as Low, Medium and High Grade Products.

Low grade products are those which have broad resin specifications (such as plastic lumber and curbside recycling containers). The manufacture of these lower grade products is a good application for post-consumer and contaminated plastic waste. Low grade products can use large percentages of recycled resins, yet the market for these products is limited. Developing new products for recycled resins, and enlarging the markets for the existing products, would help to increase their use.

Issues Concerning Low Grade Products [5]

- There are a limited number of products with broad resin specifications
- Durable products, such as lumber and recycling containers, will not provide closed-loop end-use for plastic recovered from non-durable goods such as packaging

- Demand for many products with broad resin specifications, such as plastic lumber and flower pots, are limited

Medium grade products are those which have narrower resin specifications (such as construction material and soda bottles). Regulatory or technical barriers restrict the amount of recycled resins that can be used in these products. Opportunities for using recycled resins in medium grade products have been growing concurrently with improvements in the supply of recycled resins and recycling technologies.

Issues Concerning Medium Grade Products [5]

- Regulations regarding direct contact with food
- Technical limits to recycled content
- Supply and quality of collected scrap
- Manufacturers concern about the use of recycled resins

High grade products have a very narrow resin specification (such as medical and automotive products) and are typically not good candidates for the substitution of recycled resins. These products include those with high performance standards for which the risk of possible contamination from recycled resins is often unacceptable. This category also includes applications where color matching is critical. The current variability and possible contamination of recycled resins make them unsuitable for use in these products.

Issues Concerning High Grade Products [5]

- Many products use resins which are not found in large amounts in the waste stream
- Recycled resin does not meet the material specifications standards and current technology is not capable of consistently bringing the quality of the recycled resin to these standards

3.3 Description of Evaluated Processes

Plastic products are made using many different manufacturing processes. The focus of this project was centered on the plastic manufacturing processes most commonly used. The processes examined were extrusion, film extrusion, blown film, injection molding, blow molding (extrusion and injection), and creating patterns for investment casting. The following is a basic description of each of those processes:

3.3.1 Extrusion [6, 7]

Extrusion is a common plastic processing technique that is used in a broad range of applications. During extrusion, the plastic resin is melted, heated, and then pushed through a die opening. Extrusion machines accomplish these tasks by way of one or more internal screws.

The plastic resin is first fed into the barrel of the machine through the hopper. As the resin is conveyed down the barrel by the internal screw, it is sheared between the flights of the screw and the wall of the barrel. The frictional energy produced from the shearing process heats and melts the resin while it is being conveyed. To improve the melting process, heat is sometimes also applied to the outside of the barrel. The melted resin is then extruded out the end of the barrel through an extrusion die that produces the desired cross section.

After exiting the extrusion die, the extruded plastic is fed along a conveying line and cooled by exposure to air or water. Once the extrusion is cooled, it is then processed according to the specific application (e.g., cut to size, coiled, trimmed).

Some of the factors which determine the operating parameters for this process are the type of polymer being processed, the temperature limitations, the degree of mixing, the amount of pressure required to move the polymer, the form of the extrudate, and its level of homogeneity. Another factor to consider is the flow of the melted resin through the breaker plates which are sometimes used and placed before the die. If debris is in the resin, that debris may not pass through the breaker plate. This may adversely affect the performance of the extruder by restricting resin flow through the breaker plate.

The extrusion process is the basis for other types of plastic processing. The differences in the other processes occur after the plastic has been extruded through the extrusion die. Some of these processes are thin film extrusion, blown film extrusion, and extrusion blow-molding. These three processes are described in the following sections.

3.3.2 Thin Film / Sheeting [8]

The first stage of this process is essentially the same as in extrusion. The melted plastic is pushed through an extrusion die which produces the desired cross section. Then the extrusion is stretched flat using rollers until the desired size is achieved. The sheet is air cooled and excess material is trimmed from the sides. The sheet is then put onto a roll.

Due to the nature of the process, the plastic pellets used must be of uniform size and geometry. If this is not the case, then defects in the film called "gels" occur, which are visible specks in the surface of the film. Sheets and films with gels can be undesirable in appearance applications such as product packaging. However, they can be used for lower grade applications, such as moisture barriers in building construction.

3.3.3 Blown Film [8, 9, 10]

The first stage of this process is essentially the same as in extrusion. The melted plastic is pushed through an extrusion die which produces a tubular cross section. While passing through the extrusion die, air pressure is blown inside the tube, inflating it to form a bubble shaped cross section. The product is air cooled, then the bubble is either slit to produce blown film, or pinched and cut off to produce bags, depending on product specifications. Then material is trimmed to remove the excess.

To evaluate the performance of this process, it is important to monitor the bubble, and especially its frost line. The frost line is where the molten resin re-crystallizes as a solid and where the bubble reaches its maximum diameter. The height of the frost line is determined by such factors as extruder RPM, die pressure, melt temperature, line speed, and the conditions of the cooling air. The height of the frost line affects impact strength, haze and gloss of the film, machine direction orientation, and film density. The optimum height for the frost line is typically about two times the diameter of the bubble.

Due to the nature of the process, the plastic pellets used must be of uniform size and geometry. If this is not the case, then defects in the film called "gels" occur, which are visible specks in the surface of the film. Blown films and bags with gels can be undesirable in appearance applications such as product packaging. However they can be used for lower grade applications (as listed above).

3.3.4 Extrusion Blow Molding [9, 11]

This process is similar to blown film extrusion. A tube, or parison, of plastic is lowered from an extruder. Then mold halves close around the parison and air is injected inside to expand it against the mold cavity walls. After the part has filled the cavity, the mold is separated and the excess material is trimmed from the part. This process can either be continuous or discontinuous. In the continuous process the parison is extruded and molded without stopping. In the discontinuous process the parisons are preformed and taken to another machine to be blow molded.

Some of the important parameters for extrusion blow molding are extruder RPM, die pressure, melt temperature, line speed, wall thickness, and the conditions of the injected air.

3.3.5 Injection Molding [9, 12, 13]

Injection molding of thermoplastics is a process in which plastic is melted and then forced into a mold cavity. Once in the mold, the plastic is cooled to a shape reflecting the cavity. The resulting form is usually a finished part needing no other work before assembly, or use as a finished product.

The plastic resin is first fed into the injection system through the hopper. The resin is melted by a rotating internal screw (or plunger piston). As with extrusion, the frictional energy from shearing the plastic between the flights of the rotating screw and the wall of the barrel heats and melts the resin. Heat is sometimes also applied to the outside of the barrel to assist in melting. The molten resin is then injected into the injection mold by means of the injection system until it occupies the mold cavity. After the plastic has solidified, the mold is separated and the part is ejected out of the mold. The part then has any excess material trimmed from it.

The injection system acts to both to melt the resin and to inject it into a mold. The most widely used types of injection units are conventional units and reciprocating screw units. Conventional units consist of a cylinder and a plunger that forces the molten plastic into the mold cavity. Reciprocating screw units consist of a barrel and a screw. The screw rotates to melt and pump the plastic mix from the hopper to the end of the barrel and then moves forward to push the melt into the mold.

Of the two types, reciprocating screw injection units are considered to be of better design because of their improved mixing action. The motion of the polymer melt along the screw flights helps to maintain a uniform melt temperature. It also facilitates better blending of the materials and any color agents resulting in the delivery of more uniform melt to the mold. Because of these advantages, reciprocating screw units are found in the majority of modern injection molding machines.

Some of the critical operating parameters for this process are mold temperature, screw RPM, injection pressure, shrink rate of the plastic, and throughput.

3.3.6 Injection Blow Molding [9, 11]

In this process the molten plastic is injection molded to form a hollow, preformed shape called a parison. After the plastic has solidified, the mold is separated and the parison is ejected out of the mold. The parison is then placed in a blow molding die, where it is reheated and expanded to fill the mold cavity using air pressure blown inside the parison. Once the part has expanded against the cavity walls, the mold is separated and the part is removed. Then any excess material on the part is removed.

The important parameters for this process are the same as with injection molding when the preform is being made. The blow molding portion of the process is influenced by die temperature, wall thickness, and the conditions of the injected air.

3.3.7 Investment Casting Patterns [3]

Casting is a process in which molten metal is poured or injected into a mold cavity and allowed to solidify. During or after cooling the cast part is removed from the mold and any secondary processing is then conducted. Investment casting involves the formation of an expendable ceramic investment mold around a pattern of the part to be cast. The patterns are exact models of the casting to be produced and can be made of wax or plastic. Large patterns can be formed adequately with wax, while smaller and more intricate pieces require the greater dimensional stability available with plastic. Investment casting is also referred to as the "lost wax" process because the wax pattern material from which the mold cavity is made is removed from the mold by melting.

The plastic patterns (usually made from polystyrene due to its desirable properties in the process) are made by the injection molding process. The patterns are then set into a wax base and a metal container is placed around it, creating a water tight seal. Ceramic and silica powder are mixed with water to form a ceramic slurry that is poured into the metal container. The ceramic solidifies, creating an investment mold surrounding the patterns. The plastic is then removed from the mold by burning off in a furnace and a void in the shape of the pattern remains. The plastic is removed when the ceramic mold is cured in a furnace to eliminate residual water. After curing, molten metal is poured into the investment mold, forming a metal casting which is a replica of the pattern. The finished castings are then cracked out of the ceramic mold and hand finished and deburred.

3.4 Assessing the Potential for Recycled Resin Substitution

When assessing the potential for using recycled resin in an existing application, many issues need to be considered:

- Will the substitute material meet the requirements of the product?
- Will it work well within the current processing techniques?
- Will the final product satisfactorily meet the quality and design requirements?

If the initial answer to these questions is yes, then testing of the substitute material can take place to determine what possible types and blends of recycled resin can be used. Also, the logistics of making the substitution will need to be evaluated to verify that the substitution is a feasible option within the company's organizational and financial limits.

A general assessment procedure has been developed by the Clean Washington Center [14] which provides an outline for considering the issues surrounding resin substitution. This general assessment "protocol" has been documented below, with some modifications to incorporate testing procedures developed during this project. References to the developed testing procedures have been inserted in parenthesis.

<u>…ssment Protocol for the Use of Post Consumer Recycled (PCR) Plastics</u>

<u>…1: Raw Materials and Additives Review:</u>

- Collect and analyze detailed information on resins and additives currently used (see the Material Specifications sheet in the Appendix).

- Review and discuss the effects of different recycled materials on processing and properties.
- Introduce general blending guidelines and principles of processing of blends.

Step 2: Product Review:

- Collect and analyze detailed information on product applications, critical property requirements, and product specifications (see the Product Specifications sheets in the Appendix).
- Evaluate potential for recycled material use in different products and select a product for trials.

Step 3: Process Review:

- Collect and analyze detailed information on processing parameters by product (see the Process Specifications sheet in the Appendix for each individual process).
- Assess capability of existing systems to control product properties using recycled resins.
- Evaluate need for process modifications using recycled resins.
- Select initial processing conditions for trials using recycled resins.

Step 4: Trial Run:

Test processes and parts with recycled content (see Process Testing Procedures in the Appendix). Evaluate properties and compare with specifications outlined in the Material, Process, and Product Specifications.

Step 5: Equipment Specifications:

Provide near and long term equipment specifications and suggested alterations.

6: Conclusions from Results:

Provide near and long term suggested actions for use of recycled resins.

- Products
- Minimum and maximum content
- Resin specifications and alternate suppliers
- Process changes
- Economic effect

The main objectives of this assessment procedure, as stated by the Clean Washington Center, are to:

1. Analyze product applications, critical property requirements, and product specifications.
2. Evaluate the compatibility of recycled resins with the grades or resins the company is currently using and suggesting changes when appropriate.
3. Establish minimum quality specifications for reclaimed resins to be used for each product.
4. Determine whether new specialized resin blends are needed to address specific applications.
5. Evaluate the existing equipment's capability for efficiently utilizing recycled resins.
6. Determine which equipment modifications and/or new equipment might be necessary for the company to run recycled resins.
7. Assess market opportunities.

8. Determine the company's organizational and financial ability to implement a conversion to recycled plastic resin.

3.5 Testing Procedures for Evaluating Recycled Resin Substitutions

The method for evaluating a recycled plastic suitable for substitution in a product does not differ from any other material selection process. During material selection, whether recycled or virgin material, three types of issues need to be considered. First, the material properties need to satisfy the material specifications of the product. Secondly, it needs to be verified that the material can be used in the current processes available. Lastly, the final part needs to meet the quality requirements and to perform its designed function satisfactorily.

To aid in the consideration of these issues, three types of testing procedures have been developed; Material Tests, Process Tests, and Product Tests (found in the Appendix). The procedures were developed, with input from the companies involved, to provide a general, all-encompassing format for the selection of substitute resins for different applications. Not all of the criteria within each testing procedure will necessarily apply to each company using the procedure. Each company will have different concerns depending on their processes and applications. The format used for these procedures gives companies the flexibility to tailor them to their individual needs.

3.5.1 Material Tests

Material Tests are those tests conducted on the material properties of the resin to verify its compatibility. These tests are standard material tests used to verify basic material properties. Companies normally have material specification sheets for the basic material properties they require. In many cases these material specifications have standard ASTM testing specifications [15] associated with them. The material properties are largely independent of the process used during manufacture.

A Material Specifications sheet has been developed to facilitate the determination of the material properties of the resin. The specification sheet was modeled from the Resins and Compounds Table found in the *Modern Plastics Encyclopedia '95* [16]. The material properties have been broken down into subgroups of property types. These groups are properties related to Processing; Mechanical; Thermal; Physical; and Miscellaneous. Where there are ASTM tests associated with the properties in question, the reference numbers of those tests have been provided.

It is not intended to imply that each one of these individual tests needs to be carried out. This is only a suggested list of material properties that are of typical concern to manufacturers who use plastics. Only the material properties that are important to each product's material requirements need to be tested. To emphasize this, a column has been added to the specification sheet for checking-off whether the property is critical to the particular application or not.

3.5.2 Process Tests

Process Tests are those tests conducted on the manufacturing process to see if new materials can be used within the current processes and to determine the appropriate operating conditions. Testing for optimum equipment operating conditions is dependent on the process used during manufacturing and requires identification of the equipment operating parameters that influence the final product quality.

Process Testing Procedures have been developed for each of the targeted plastics manufacturing processes. These are Extrusion, Blown Film Extrusion, Thin Film / Sheet Extrusion, Injection Molding, Extrusion Blow Molding, and Injection Blow Molding. The testing procedures were modeled from the Plastic Film Recycling Process Assessment developed by the Clean Washington Center [17]. Tests for other plastic manufacturing processes can be easily developed using this model. Each of the procedures is broken down into sections describing the Trial Set-Up, the Start-Up, and the Process Run. These procedures offer a way to evaluate the operating parameters for substitute materials.

A Process Specifications sheet was created for each of the processes to help document testing and record observations. At the top of the sheet is a table to document information about the resin being tested. The important parameters for each process are listed in the Process Testing Data Chart located at the bottom of the sheet.

3.5.3 Product Tests

Product Tests are tests conducted on the final product to check its ability to meet usage requirements and to verify conformance with design specifications. Tests on the products are essentially the quality control and inspection tests that will be applied during and after production.

A Product Specifications sheet has been developed to facilitate the evaluation of the final product. The final product requirements have been broken down into subgroups relating to the type of manufacturing processes used to produce the part. These groups of properties are related to Blown Film, Thin Film, Sheet Extrusion; Extrusion; Injection Molding; Blow Molding (Extrusion and Injection); and Investment Casting Patterns. Where there are ASTM tests associated with the requirements in question, the reference numbers of those tests have been provided.

It is not intended to imply that each one of these individual tests needs to be carried out. This is only a suggested list of product requirements that are of typical concern to manufactures who use plastics. Only the quality requirements that are important to each individual product need to be tested. To emphasize this, a column has been added to the specification sheet for checking-off whether the property is critical to the particular application or not.

3.6 Case Studies at Companies in Rhode Island

3.6.1 Background and Methodology

To investigate potential uses for recycled resins, studies were conducted at manufacturing companies located throughout Rhode Island. The situation at each company was evaluated through the assessment of the material, process, and product requirements for their existing manufacturing processes.

3.6.1.1 Initial Evaluation

In previous work [9], a survey of Rhode Island companies was conducted concerning their use of plastics and their willingness to look into using recycled resins. From that list, and through other contacts, a group of companies were selected where case studies regarding recycled plastic usage could be conducted. The companies were chosen to represent a diversified range of polymers, products, and processes. The investigation of a wide range of applications provided a broad viewpoint from which to identify the best opportunities for using recycled plastics. The selected companies were then contacted over the phone to verify their interest and to set up on-site visits to their facilities.

During the visits with the companies, the use of plastics in their products was discussed. This included the types and quantities of resin they use, their processing technologies, their current waste disposal situation, their product requirements, and any other information which was important to their products. A tour of their manufacturing facilities was also conducted to gain a first-hand understanding of their manufacturing processes.

Once a better understanding of the product requirements was achieved, discussion was then shifted to the possible benefits and problems associated with substituting recycled plastics into them. For each problem that was sighted, possible solutions were sought. By the end of the discussions, the prospective products for resin substitution, if any, were determined. For those products, a list of the resins used and important specifications was obtained so that substitute recycled resins could be determined. The level of follow-up that occurred with each company depended on the amount of potential that existed for using recycled resins.

3.6.1.2 Sourcing Substitute Resins

In the cases where the potential for using recycled resins was found, the next step in the methodology was to find an adequate source of substitute resin. To do this, a list was needed of available reclaimers and reprocessors of recycled plastics.

The American Plastics Council (APC) is a trade organization which represents a broad cross-section of the plastics industry. They maintain a database of post-consumer plastic handlers and processors which they make available upon request. They were contacted for a list of reputable New England resin suppliers, but as a trade organization they will not recommend one company over another. The APC supplied a listing of processors (in the Northeast and across the country) which contained contact information, resin handlers, and the processing available at each facility. The information received was too broad to conduct an effective search based solely on resin type. Therefore, the facilities to be initially contacted were selected based on their proximity to Rhode Island. The primary resin supplier selected was The Plastics Group located in Woonsocket, Rhode Island.

The Plastics Group is a subsidiary of Ralco Industries and the only Rhode Island recycled resin handler and processor listed in APC's database. They specialize in the compounding and distribution of post-industrial thermoplastic resins; mainly polypropylene, polystyrene, and polyethylene. They reclaim plastics from many companies in the area, reprocesses it back into a useable raw material form, and either send it back to the companies for reuse or send it to another customer who can use the material. They also produce their own virgin resins.

The Plastics Group was given a list of material specifications for the resins where substitutions were to be considered. They in-turn suggested a few possible resin matches suitable for substitution. Once this information was received, the process began of re-contacting the companies to persuade them to test the alternate material.

3.6.1.3 Testing of Substitute Resins

At the time this thesis was completed, the testing of substitute resins within the companies' processes was being pursued. There have yet to be any tests conducted at the participating companies. The reasons for this can be attributed to a number of possible factors. The underlying factor, however, is the low level of priority that this project was given by each company relative to their other projects and concerns. Their main priorities are the concerns which have a direct and definite impact on the welfare of their business. Until those main priorities can be resolved, the substitution of recycled resins for virgin will be a lesser concern.

Also, many of the companies investigated use plastics on such a small scale, and it plays such a limited role in their business (less than 10% of the total material used in their products), that the potential cost savings for using recycled plastics is small. The recycled resin is neither substantially beneficial to buy or in an economical quantity for the resin processors to supply. The small quantity of plastic used in their products also results in a low priority for recycled resin substitution. To them the risk is much greater than the benefit. Furthermore, such small use applications do not readily provide any long-term solutions to the development of end-use markets.

Examples of these and other issues encountered are presented in the following case studies with each company.

3.6.2 Case Studies

3.6.2.1 American Industrial Casting, Inc.

Location:	Cranston, RI
Plastics Process Used:	injection molding
Products:	investment casting patterns

Material Used:	Production Capacity:
Medium Impact Polystyrene, PS (in-house)	5200 lb./year
Medium Impact Polystyrene, PS (made by outside company)	20,000 lb./year

Background

American Industrial Casting (AIC) is a small, non-ferrous investment casting firm. They produce a range of diversified, precision cast products for both commercial and defense industries. Defense related components that are used in radar, satellites, night vision equipment, missiles, and tanks comprise approximately 48% of AIC's sales. AIC is a preferred vendor to companies such as Raytheon, Martin Marietta, and Eastman Kodak.

Applications

In the investment casting process, as described in the previous section, the ideal material used to make the patterns is wax. However, smaller and more intricate pieces require greater dimensional stability which is difficult to achieve with wax, but is available with plastic. AIC uses polystyrene plastic in the injection molding process to make those smaller patterns. Since they market a diverse product line of precision cast parts, their products have strict dimensional tolerances. However, the patterns they use to make the molds do not have cosmetic or odor concerns. Because the plastic is not present in the final product, this process has the potential for using recycled plastics.

AIC participated in the DEM's initial project on feedstock substitution [3]. In that project, they conducted testing of 100% post-consumer polystyrene supplied by the National Polystyrene Recycling Co. for two types of parts. The results were extremely favorable in terms of performance and economics, and AIC pursued further testing of other parts on their own after the end of the project. Unfortunately, the supplier of the recycled polystyrene was not able to supply AIC with resin of the same quality and properties on subsequent deliveries. AIC tested the plastic they received, but it did not meet their performance requirements as before. Therefore, AIC discontinued use and testing of the recycled polystyrene. Their requirements for the polystyrene are as follows:

1. The plastic must have good injection moldability, i.e. it must flow and fill the mold at low temperatures.
2. It must be dimensionally stable and exhibit little shrinkage.
3. The plastic should cool quickly and eject easily from the mold.
4. The finished plastic piece must have good surface smoothness.
5. The plastic should leave little or no residue on mold walls upon removal and not react with the mold walls.

For the current project, AIC was considering a recycled polystyrene substitution from a different supplier. If a consistent, high quality supply could be ensured they would consider using the polystyrene in both in-house and contracted applications. However, the annual amount of polystyrene used in-house and contracted by AIC is relatively small (5200 lb. and 20,000 lb. respectively). As a result, the economic motivation for AIC to consider a switch will be small if the risk of inconsistent properties and quality remains. It may also not be cost competitive to buy the recycled resin in such a small quantity due to the logistics of the company supplying the resin.

Investigation and Results

During the initial visit with AIC, the primary focus of the discussion was to find out why they stopped testing the recycled resins as a pattern material. The reason, as stated above, was because the recycled polystyrene they received on subsequent deliveries could not meet their performance requirements as the original supply had done.

Due to the high expectations and publicity resulting from the reported success of the first trial, AIC was reluctant to consider continuing the effort during this project. From their perspective, they received excessive attention for a relatively small use of recycled plastic (less than 10% of their pattern material) and were reluctant to repeat the experience. Despite their past experience, they did agree to consider trying to use recycled polystyrene from another source if the properties could be guaranteed.

AIC supplied a list of properties of the polystyrene that they use (see Appendix). Recycled polystyrene was sourced through The Plastics Group. One of the types of plastics they reprocess is a high impact polystyrene (HIPS). The Plastics Group had stated that they would supply a small sample for testing. Before trying any substitute material, AIC has expressed that they want to have written documentation on the material properties and their level of guarantee. This was relayed to The Plastics Group and at the time of this report, they had not yet supplied the information.

Follow-up

At the moment, there seems to be a genuine potential for the substitution of recycled polystyrene as AIC's investment casting pattern material. The recommended follow-up would be that The Plastics Group be re-contacted to supply both the written material specifications and a sample of plastic to test. Naturally, AIC will also need to be contacted to request them to consider testing the resin.

The logistics of long term use of the substitute material still needs to be evaluated. As the quantity of plastic used by AIC is relatively small, they do not have the luxury of a lower material cost from buying it in large quantities. As the situation at AIC is typical for the investment casting industry as a whole, the long-term potential of using investment casting patterns as an end-use market of polystyrene should be re-evaluated.

3.6.2.2 A.T. Cross Co.

Location:	Lincoln, RI
Plastics Process Used:	injection molding
Products:	ink refills and internal parts (possibly packaging)

Material Used:	Production Capacity:
Polycarbonate, Polypropylene, Polyethylene, Acrylic, Nylon 6, and Delron. (in-house production)	< 20,000 lb./year

Background

A.T. Cross is a major international manufacturer of fine writing instruments and operates mainly in the writing instrument business. The types of writing instruments they produce include ball point pens, mechanical pencils, rolling / porous point pens and fountain pens.

Applications

A.T. Cross uses plastics in the components of their writing instruments, ink refill cartridges, internal parts, and some packaging. Since A.T. Cross concentrates on the market of high quality writing instruments, their products have stringent cosmetic requirements. In the past they have tried blending regrind from their processes with virgin resin in their products. The result of the effort, however, was a noticeable degradation in the cosmetic appearance.

Investigation and Results

During the initial visit with A.T. Cross, the status of plastic use in their products was discussed and an on-site tour was conducted. The situation at A.T. Cross is typical of a company that produce small parts. The amount of plastic used to make the parts typically comprise only 10% of the total plastic needed to produce the part. The other 90% makes up the sprue and runner system of the injection molding process. They have tried to regrind and reuse their scrap, however from their experience they can only use less than 10% regrind in their products due to a resulting decline in product quality. They have found a few in-house uses for their scrap (e.g. part carriers in the factory), but they currently send most of their scrap to The Plastics Group.

The areas in which the use of recycled resins were viewed to have some potential were with their ink refills and internal parts. These parts have no serious cosmetic requirements. The packaging used for their gift boxes, which are made by another facility, were also to be considered. In total, they have many different small plastic parts and were asked to evaluate which of those parts have potential for resin substitution. Once those items had been established, A.T. Cross was to supply a list of the resins that are used in them. Due to shifting priorities and interests at the company, this task had not been accomplished at the time of this report.

Follow-up

Due to the small amounts of plastic used by A.T. Cross and their stringent cosmetic requirements, recycled resin substitution is highly unlikely. Beyond the quality issues, for the quantities of plastics they use, there may not be enough economic motivation to encourage them to pursue using recycled resins. It should also be noted that currently they are even unable to reuse most of the plastic scrap they generate internally due to those quality constraints. As no substantial potential for substituting recycled resins exists, it is felt that any follow-up with this company will yield few results.

3.6.2.3 Taco, Inc.

Location:	Cranston, RI
Plastics Process Used:	injection molding
Products:	pump impeller, mounting interface, cover (all made by outside company)

Material Used:	Production Capacity:
Pump Impeller: 30% Glass Filled Polypropylene	18,400 lb./year
Mounting Interface: Mineral Filled Nylon 6/6	1,475 lb./year
Cover for Components: Valox (Polyester, thermoplastic)	1,600 lb./year

<u>Background</u>

Taco is a manufacturer of pumps and valves for the heating and air conditioning industry, supplying to both the consumer and industrial markets. They sell their products both domestically and abroad. The use of plastics in their products compared to other materials, such as metals, is minimal. However they have supplied samples, drawings, and specifications for those parts of their products in which plastics are used.

<u>Investigation, Applications and Results</u>

There were three different parts under investigation: 1) the mounting interface piece between the motor and ball valve of a motorized zone valve, 2) a pump impeller, and 3) a protective casing for electro-mechanical components. The only requirement for these parts is that they meet the performance criteria for which they have been designed.

It is important to note that all three of the investigated parts are made from engineering grade resins. The environments in which those parts perform their function necessitate the use of resins that can withstand those conditions. The substitution of recycled resins of the same type is not possible due to the lacking availability of recycled engineering resins. For any substitution of unlike resin types to be considered, a thorough engineering analysis would have to take place to evaluate the design parameters for using a different material. This level of engineering analysis was outside the scope of this project.

Follow-up

A direct resin substitution for all three of the components investigated is not possible due to a lack of available recycled engineering resins. There is a large level of risk and liability associated with the products in which those plastic components are used, which is what necessitates the use of engineering grade resins. As no substantial potential for substituting recycled resins exists at this company, it is felt that any follow-up, such as the suggested engineering analysis, will yield few long-term results.

3.6.2.4 Kenney Manufacturing Co.

Location:	Warwick, RI
Plastics Process Used:	extrusion
Products:	vertical window blinds, curtain rods

Material Used:	Production Capacity:
Curtain Rod Covering: Low Density Polyethylene (LDPE)	500,000 lb./year
Window Blinds: Polyvinyl chloride (PVC)	700,000 lb./year
Injection Molded Ornamentation: Unknown (contracted)	Unknown

Background

Kenney manufactures window blinds, drapery hardware, curtain rods, and similar products. Due to the importance of overall appearance in their business, their products have stringent cosmetic and ultra-violet sunlight stabilization requirements.

Applications

Of all the companies investigated during this project, Kenney uses the largest amount of plastics in their products. The products that comprise the bulk of Kenney's resin use are their white vertical window blinds (PVC) and coverings for their curtain rods (currently LDPE, however they were in the process of switching over to polypropylene). They are very reluctant to use any recycled resins in these two products due to the quality concerns mentioned above, as well as due to their strength and rigidity requirements for their vertical blinds. Despite this, replacement resins that meet their material specifications were sourced for these two products to provide some suggested material alternatives.

Kenney also sells drapery and curtain rod ornamentation that are made from injection molded plastic by an outside vendor. Many of these parts are made from a black colored plastic or are covered by a coat of metallic paint. These types of parts would lend themselves very easily to the use of recycled resins.

Investigation and Results

After touring Kenney and assessing the potential for resin substitution, a list of the material properties was obtained for the plastics they use for their window blinds and curtain rod coverings. Replacement resins which have the same properties were sourced through The Plastics Group, even though Kenney had no interest in substituting recycled resin into their virgin feedstock.

Also, substitute resins for the injection molded ornamentation was planned to be investigated once Kenney provided the necessary information. However, Kenney was having quality problems will the current vendor, so they wished to resolve those problems before they look into resin substitution.

During the tour, it was also noticed that Kenney generates a large amount of plastic scrap during their plastic color changes. The Plastics Group was contacted to see if they could use some of Kenney's plastic scrap, and they visited Kenney to assess the situation. While discussing disposal and reprocessing alternatives for the plastic, the representative mentioned that they supply both virgin and post-industrial resins. During the conversation, the representative from The Plastics Group was able to alleviate Kenney's original concerns and superstitions with using recycled resins. As a result, Kenney agreed to consider the testing of a natural HDPE post-industrial resin for the covering of their curtain rods. Kenney would add additives, such as color, to the resin themselves.

A sample of the resin from The Plastics Group had been sent over to Kenney. Unfortunately, it was sent over pre-maturely as The Plastics Group wanted reimbursement for the plastic sample due to its large size, and the price had yet to be negotiated. At the time this report was written, the situation had yet to be resolved.

Follow-up

There is a great potential for the use of post-industrial resin within Kenney's in-house production of curtain rods and their contracted injection molded ornamentation. The major road-block to testing the possible substitution is the current misunderstanding between the company and the resin supplier about payment for the sample. One possible solution was offered through the DEM, suggesting financial assistance to expedite the testing of the material. The follow-up that is suggested is to continuously monitor the situation and offer assistance to both sides to resolve the situation. If testing does occur, then monitoring the testing procedure is also suggested.

With regard to the injection molded ornamentation, through talking with The Plastics Group, it was discovered that they recognized the ornamentation during their visit as coming from one of their own plastics customers. According to The Plastics Group, they have supplied that customer with post-industrial recycled material in the past. Any future follow-up in this area would be to contact the company directly to investigate their use of recycled resin. It should be noted, however, that Kenney may have finally changed suppliers at this point.

3.6.2.5 Turex, Inc.

Location:	Harrisville, RI
Plastics Process Used:	thin film extrusion
Products:	thin film, primarily for food packaging

Material Used:	Production Capacity:
Polyethylene (in house production)	> 1,000,000 lb./year

Background

Turex is a manufacturer of thin film located in Harrisville, RI. Their films are primarily used for food packaging, or other FDA regulated uses like liners for toothpaste tubes.

Applications

As food packaging must meet Federal Food and Drug Administration laws, which do not allow direct contact between foodstuffs and recycled materials, Turex was not a candidate for resin substitution. However, insight into the limitations of using recycled resins in film manufacture was gained.

Investigation and Results

Turex had experimented in the past with using regrind within the thin film extrusion process. Due to the nature of the film process, the plastic pellets need to be of uniform size and geometry. If this is not the case, then a defect in the film called "gels" occurs, which are visible specks in the surface of the film. Films with gels are undesirable in appearance applications such as food packaging, however they can be used for applications like garbage and grocery bags, and construction sheeting. The films that do not meet the quality standards of Turex's customers are sold through another company to other customers that do not have the same high standards.

Follow-up

Although no direct follow-up with this company is suggested, the use of recycled resin in lower grade film products, such as garbage and grocery bags, should continue to be promoted. There is no known reason why those applications cannot use recycled resins to produce them. Another possibility is using the recycled film between layers of plastic film which can contact food material (co-extrusion).

3.2.6.6 Atlantek, Inc.

Location:	Wakefield, RI
Plastics Process Used:	foam blowing, spin-molding
Products:	packaging material, end-covers

Material Used:	Quantity:
Packaging material: Ethafoam (polyethylene foam)	1,000 lb./year
End covers for Card Printer: Krydex (fire-rated acrylic/PVC)	< 1,000 lb./year

Background

Atlantek is a manufacturer of high quality ID card printers located in Wakefield, Rhode Island. Their customers have been primarily state departments of motor vehicles and Polaroid. It is a company that is growing quickly and is looking to expand its production and throughput without sacrificing quality or cost.

Applications

A possible application for using recycled resins at Atlantek is with the packaging material used to ship their printers. They are currently made from a plastic polyethylene foam. They would consider purchasing a packaging foam made from recycled resin if the design of the packaging material were not altered and the resin performance of the substitute is equal to the original resin.

The end covers from one of their models for ID card printers was also considered. Once again, an engineering resin was used for the covers and the quantity of the plastic used in them was small.

Investigation and Results

Atlantek was contacted near the end of this project through unrelated work. They suggested that a possible recycled resin substitution could take place for their packing material. As polyethylene (HDPE and LDPE) is commonly collected from the post-consumer waste stream, it seems natural that it should be used as feedstock for polyethylene foam packaging. It is felt that using HDPE along with a chemical blowing agent should be able to create a comparable foam packaging material.

Follow-up

Although Atlantek does not directly have potential for resin substitution, it is suggested that the potential for using recycled plastic in foam packaging applications should be investigated. There seems to be a large potential in the foam packaging industry for the use of post-consumer resins, as they have few of the concerns that many other industries seem to possess.

3.7 Strategies for Promoting the Use of Recycled Resins

3.7.1 Problems With the Current Strategy

Using the current method, finding applications for potential resin substitution has not produced the desired results. Finding recycled resins for specific applications has been ineffective because there may not be a recycled resin that can meet the requirements of the application investigated. This was the case with many of the companies involved in this project. For the most part, the products that they produce are medium and high grade products, which typically are not good candidates for recycled resin substitution.

Another problem is the level of interest the companies have in using recycled resins in their products. During this project, a healthy, initial interest from the companies was felt. However, that interest tapered away due to the low level of priority that was placed on the project by the companies. The main priorities for the companies are the concerns that have a direct and critical impact on their welfare. This type of research project which represents risk without clear benefits or incentives ranks low in priority. In cases where the companies' interests in using recycled resins has been initiated internally, they have placed it as a high priority. With these companies, the probability for establishing a successful resin substitution is much greater.

3.7.2 Recommended Strategies

The main concern of the companies involved in the study was with the properties and quality of the plastic they use as feedstock. To address those concerns, recycled resin suppliers need to offer a range of materials with guaranteed properties which are accepted as alternatives to virgin materials. By doing this, recycled resins have a better chance to be successfully marketed to medium and high grade applications. Guaranteeing properties will alleviate most of the uncertainties that companies have about using post-consumer plastics within their applications. As previously stated, the manufacturer's first concern is to meet the performance, consistency, and material requirements of their customers. Meeting these requirements can be difficult to achieve using recycled post-consumer plastics, especially those with varying properties.

For plastics recycling to operate successfully on its own, a supply and demand relationship between resin suppliers and manufacturers needs to be established. The best way for this relationship to grow is through the workings of a competitive market. Realistically, the main motivation for both the manufacturer and supplier will be economic. The supplier wants to make money and the manufacturer wants to save money without sacrificing quality.

The best salesmen for the suppliers are typically not third-person projects promoting recycled resin use, such as this particular project, but the suppliers themselves. It is their job to sell their recycled resin and convince the manufacturer that using recycled resin in their products is worthwhile. They are the only ones who can truly alleviate the manufacturers' fears of using recycled resin are the suppliers. They are aware of the typical concerns of manufacturers and are the ones to whom those concerns are addressed. Therefore, the suppliers are the ones who should promote the resins they supply because they know about the inherent advantages and limitations of using them.

The perfect example of this type of promotion strategy is with the inter-relations between this project, Kenney Manufacturing, and The Plastics Group. During the initial visit with the engineers at Kenney, they had decided that they could not use recycled resins in their products due to their stringent color, strength, and quality requirements. However, it was noticed that Kenney had a lot of plastic scrap that they landfill, so The Plastics Group was contacted to see if they could use any of it.

A representative of The Plastics Group visited Kenney to examine the scrap plastic. While discussing disposal and reprocessing alternatives for the plastic, the representative also mentioned that The Plastics Group supplies both virgin and post-industrial resins. During the conversation, the representative was able to alleviate Kenney's concerns and superstitions with using recycled resins. As a result, Kenney is currently considering the testing of a natural HDPE post-industrial resin for the covering of their curtain rods. They are also considering the scrap collection and reprocessing alternatives available from The Plastics Group.

The position of The Plastics Group as a supplier of resins is very advantageous. They have many material options to provide to their customers. They sell post-consumer resins alongside virgin resins. They can collect and reprocess a company's plastic scrap for their reuse, or to sell to another company. Due to these numerous options, The Plastics Group can "get their foot in the door" and offer a variety of solutions.

From this experience, the most effective method to increase the use of recycled resins would be to uncover the companies where potential for using recycled resins exists and then make the suppliers aware of them. Once that has been done, the manufacturers and suppliers should be able to work together with minimal guidance. The role of any project promoting the use of recycled resins should not be the one of the "middle man". The project can only effectively make resin suppliers aware of the manufacturers with potential end-use markets and bring them together. If using recycled resins is truly feasible, it will be determined by the two parties in question.

3.8 Conclusion

The inherent limitations involved with recycling plastics are why the development of end-use markets needs special consideration. In the short term, projects have been created across the country to promote the use of recycled plastics in manufacturing and to develop end-use markets. Although this is a worthwhile task, the long term goal must be to make plastic recycling and activity that is self-promoting and self-sustaining. This must be done by offering a range of materials with guaranteed properties that are accepted by industry as alternatives to virgin materials. Only then can plastic recycling operate successfully.

Chapter 3 References

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Chapter Four: Conclusion

4.1 Findings from Research

A proposed end-of-life classification system was developed as a way to assess the disposal possibilities of product assemblies. Its intended purpose is to demonstrate how changes in the materials and additives used may improve a product's design for end-of-life. This was demonstrated though the conduction of case studies using this system.

The proposed classification system was designed to be used by both product designers and dismantlers, since possible end-of-life destinations are identified for several material compositions and combinations. This information is needed to help design the product for the minimal amount of disassembly required for disposal. The disposal methods selected will largely be driven by profit and less by environmental concerns. However, current and future regulations on disposal procedures will force dismantlers to consider environmental issues during their material and end-of-life selection processes.

For the materials which are to be recycled, end use markets must exist. Otherwise, there will be no demand for their use. Without that demand, the economics for disassembly products for material recycling will not be practical. The infrastructure of metals recycling is well established, in that closed-loop recycling currently takes place extensively. Other materials recycling industries, such as those for plastics, are less well established which is why end use applications for these materials must be sought out. This was the objective in investigating uses for post-consumer and post-industrial resins in the range of applications.

During the investigation for end-use markets for recycled plastics, it was discovered that the current methodology which is used did not produce the desired results. In addition, the current methodology only offers short term solutions, if any at all. The long term goal must be to make plastic recycling an activity that is self-promoting and self-sustaining. This must be done by offering a range of materials with guaranteed properties that are accepted by industry as alternatives to virgin materials. Only then can plastic recycling operate successfully.

4.2 Future Work

This research created a strong foundation for an end-of-life classification system. However, as technology and economics changes, so should the classification system to incorporate them. There is also room for improvement in the current system. The following recommendations are made for the system's future development, as well as for future research in supporting areas:

1. <u>Incorporate material quantities, part weight, and material cost into the system.</u>

   A major assumption that was made during the development of the Material Table rankings was that the materials would be in an amount significant enough to consider each end-of-life destination. The current system still leaves the user of the system to evaluate the economics of quantity themselves. If only a small quantity of the material is in the product, then a large outside supply of the material must already exist or the inherent costs become too great. Conversely, if there is a large amount of material in a product that is not commonly recycled, then this large supply might promote interest in its reprocessing, thus increasing its end-use demand.

Also, the actual cost of the material was not incorporated into the system. It was felt that the quantity and demand for the material was more important than the material cost itself, as those issues are what drive the cost. However, it may be of benefit to somehow incorporate those material costs into the system.

2. "Itemize" the rankings and effect factors.

To simplify the classification system, the two economic portions used to form the rankings and effect factors were combined into a single number. It is suggested that those two portions be itemized in future work to help clarify the weight of each portion on the total ranking or factor. That way the user will know if the end-of-life preferences are primarily due to the process cost or end-use market demand, or both.

3. Continue research on end-of-life rankings and effect factors.

The information which is used in the classification system's rankings should continue to be collected. Once the effects of additives and material combinations on end-of-life are researched, more accurate information will become available for the classification system to use. This task should also be a continuous process as the technology and infrastructure of each end of life destination changes. Also, the development of a Materials Compatibility table for recycling metals should be investigated further.

This research also provided valuable insight in the strategies which should be used to effectively promote recycled resin use and establish a plastics recycling infrastructure. The following recommended are several recommended strategies that should be considered before continuing work in this area:

1. <u>Identify applications for resins currently collected and in surplus.</u>

   While it is tempting to approach companies that appear open to the concept of recycled feedstock substitution, this project found that many have products with specifications that cannot be met by currently available recycled resins. A more logical approach is to take a known resin supply for which demand is lacking, and review manufacturing processes for potential applications. This not only avoids the problems and time spent searching out supply, but looks to create a solution to an existing oversupply problem.

2. <u>Develop new products specifically designed for using recycled plastic.</u>

   When there is a lack of potential applications for a resin in surplus, the next step is to develop new applications. These applications will most likely be in areas which would replace materials other than plastics. This type of strategy again avoids the problems of searching out a resin supply and creates a solution to an existing oversupply problem.

3. Develop the capacity of resin suppliers to be able to offer a range of recycled resins with guaranteed properties.

In order for these efforts to be successful, especially for mid to high range products, resin suppliers must be able to offer performance guarantees for recycled resins at the same level they are offered for virgin resins. Few resin suppliers offer these guarantees now. Special environmental organizations could facilitate work directly with resin suppliers to help them develop this level of sophistication. Once this has been accomplished, the resin suppliers will be in the position to market their recycled resins directly without the need for the involvement from those environmental organizations.

4. Increase the dialogue between coordination among others doing similar work.

Several other states, many in the northeast, are doing similar work. These individual efforts are often conducted with meager resources, affecting the success of the project. Increased networking, from regular discussions to coordinated regional projects, would stretch the available resources and benefit all involved. The National Recycling Coalition or Northeast Recycling council are both viable options for creating increased interaction.

5. Modify the tasks of the current strategy to incorporate the recommendations above.

For future projects promoting the use of recycled resins in existing applications, the first step should be to identify companies where potential exists. This can be done in the same manner as the methodology used during this project. Then the information regarding any interested companies with potential for resin substitutions should be posted in a centralized location, as mentioned above. It would be up to the handlers and reprocessors to take the initiative to contact those interested companies that have a potential for substitution. Their goal is to sell their resins, so it is a reasonable assumption that they would be willing to take that initiative. Like the APC, the position of any recycling promotion project should not be one to recommend one resin supplier over another, but to promote the industry as a whole.

Appendix A: End-of-Life Classification System

Plastics Material Table

		End-of-Life Rankings								
		Recycle			Reprocess				Landfill	
	Material	recycled, without need for material segregation	recycled, segregation of co-mingled materials or special processing required	reground and used as part fillers	reprocessed chemically or thermally to recover basic material constituents	incineration used to recover heat energy and material	incineration used to recover heat energy and material, with toxic controls	unique process used for hazardous waste treatment	landfill / normal waste	landfill / hazardous waste
P1	ABS (acrylonitrile-butadiene-styrene)	70	50	60	75	75	60	30	85	40
P2	ASA, SAN (styrene-acrylonitiriles)	50	40	60	75	75	60	30	85	40
P3	EPM / EPDM (ethylene-propylene rubber)	50	40	60	75	75	60	30	85	40
P4	HDPE (high-density polyethylene)	90	70	60	75	80	65	30	85	40
P5	LDPE (low-density polyethylene)	90	70	60	75	80	65	30	85	40
P6	PA (polyamide; nylon)	50	40	60	75	80	65	30	85	40
P7	PBT (polybutylene terephthalate)	50	40	60	75	75	60	30	85	40
P8	PC (polycarbonate)	70	50	60	75	75	60	30	85	40
P9	PEI (polyehterimide)	50	40	60	75	75	60	30	85	40
P10	PET (polyehtylene terephthalate)	90	70	60	75	80	65	30	85	40
P11	PMMA (polymethyl methacrylate; acrylic)	50	40	60	75	75	60	30	85	40
P12	POM (polyoxymethylene; acetal)	50	40	60	75	75	60	30	85	40
P13	PP (polypropylene)	80	60	60	75	80	65	30	85	40
P14	PPE, S-B (polyphenylene ether)	50	40	60	75	75	60	30	85	40
P15	PPO (polyphenylene oxide)	50	40	60	75	75	60	30	85	40
P16	PS (polystyrene)	80	60	60	75	80	65	30	85	40
P17	PVC (polyvynil chloride; vynil)	75	55	60	75	75	60	30	85	40
P18	SBS	50	40	60	75	75	60	30	85	40
P19	TPU (thermoplastic urethane)	50	40	60	75	75	60	30	85	40
P20	PUR (polyurethane)	0	0	60	75	80	65	30	85	40
P21	Phenolics	0	0	60	60	30	50	30	85	40
P22	Polyester	0	0	60	60	30	50	30	85	40
P23	Rubber	0	0	60	60	30	50	30	85	40
P24	Unknown Composition	25	25	50	60	50	50	30	85	40

Metals Material Table

		End-of-Life Rankings								
		Recycle			Reprocess				Landfill	
	Material	recycled, without need for material segregation	recycled, segregation of co-mingled materials or special processing required	reground and used as part fillers	reprocessed chemically or thermally to recover basic material constituents	incineration used to recover heat energy and material	incineration used to recover heat energy and material, with toxic controls	unique process used for hazardous waste treatment	landfill / normal waste	landfill / hazardous waste
M1	Steel, low carbon	90	90	50	75	0	0	30	80	40
M2	Steel, medium carbon	90	90	50	75	0	0	30	80	40
M3	Steel, high carbon, tool	90	90	50	75	0	0	30	80	40
M4	Steel, high carbon, stainless	90	85	50	75	0	0	30	80	40
M5	Steel, high carbon, maraging	90	85	50	75	0	0	30	80	40
M6	Iron	90	75	50	75	0	0	30	80	40
M7	Aluminum, alloys	95	85	50	75	0	0	30	85	40
M8	Beryllium	85	75	0	75	0	0	30	80	40
M9	Magnesium	95	75	20	75	0	0	30	85	40
M10	Titanium, alloys	95	75	20	75	0	0	30	80	40
M11	Chromium	70	55	0	75	0	0	30	80	40
M12	Copper	90	85	50	75	0	0	30	80	40
M13	Copper, brasses	90	85	50	75	0	0	30	80	40
M14	Copper, bronzes	90	85	50	75	0	0	30	80	40
M15	Copper, other alloys	90	85	50	75	0	0	30	80	40
M16	Nickel, alloys	90	75	50	75	0	0	30	80	40
M17	Cobalt, alloys	70	55	0	75	0	0	30	80	40
M18	Maganese, alloys	70	55	0	75	0	0	30	80	40
M19	Bismuth, alloys	70	60	0	75	0	0	30	80	40
M20	Lead, alloys	85	75	0	75	0	0	50	0	50
M21	Zinc, alloys	90	80	0	75	0	0	30	80	40
M22	Tin, alloys	90	80	50	75	0	0	30	80	40
M23	Tantalum, alloys	70	55	0	75	0	0	30	80	40
M24	Tungsten, alloys	90	75	0	75	0	0	30	80	40
M25	Molybdenum, alloys	70	55	0	75	0	0	30	80	40
M26	Gold	100	100	0	75	0	0	30	80	40
M27	Gold, alloys	100	100	0	75	0	0	30	80	40
M28	Silver	100	100	0	75	0	0	30	80	40
M29	Silver, alloys	100	100	0	75	0	0	30	80	40
M30	Platinum	100	100	0	75	0	0	30	80	40
M31	Platinum, alloys	100	100	0	75	0	0	30	80	40
M32	Palladium, alloys	95	80	0	75	0	0	30	80	40
M33	Gallium, alloys	70	55	0	75	0	0	30	80	40
M34	Silicon, alloys	70	55	20	75	0	0	30	80	40
M35	Mercury	70	45	0	75	0	0	30	0	40
M36	Rhodium, alloys	70	55	0	75	0	0	30	80	40

Miscellaneous Material Table

	Material	End-of-Life Rankings								
		Recycle			Reprocess				Landfill	
		recycled, without need for material segregation	recycled, segregation of co-mingled materials or special processing required	reground and used as part fillers	reprocessed chemically or thermally to recover basic material constituents	incineration used to recover heat energy and material	incineration used to recover heat energy and material, with toxic controls	unique process used for hazardous waste treatment	landfill / normal waste	landfill / hazardous waste
C1	Glass	90	80	70	20	0	0	30	85	40
C2	Ceramic	50	30	40	20	0	0	30	85	40
C3	Wood	0	0	90	20	90	80	30	85	40
C4	Paper	80	70	90	20	90	80	30	85	40
C5	Cardboard	80	70	90	20	90	80	30	85	40
C6	CFC (Chloroflourocarbon)	80	40	0	40	0	0	80	0	0
D7	PCB	75	75	50	90	70	60	75	85	40
D8	Wires	75	75	50	90	70	60	75	85	40
D9	Misc. Electrical Components	75	75	50	90	70	60	75	85	40
D10	Small motors	75	75	50	90	70	60	75	85	40

Plastics Additive Table

	Coatings, Additives, Fillers	End-of-Life Effect Factors								
		Recycle			Reprocess				Landfill	
		recycled, without need for material segregation	recycled, segregation of co-mingled materials or special processing required	reground and used as part fillers	reprocessed chemically or thermally to recover basic material constituents	incineration used to recover heat energy and material	incineration used to recover heat energy and material, with toxic controls	unique process used for hazardous waste treatment	landfill / normal waste	landfill / hazardous waste
AP1	Antioxidants	0.90	0.90	1.00	0.95	0.85	0.85	1.00	1.00	1.00
AP2	Antistatic Agents	0.90	0.90	1.00	0.95	0.85	0.85	1.00	1.00	1.00
AP3	Biostabilizers	0.90	0.90	1.00	0.95	0.95	0.95	1.00	1.00	1.00
AP4	Chemical Blowing Agents	0.70	0.50	0.80	0.70	0.85	0.85	1.00	1.00	1.00
AP5	Cross-Linked Agents	0.75	0.75	1.00	0.90	0.95	0.95	1.00	1.00	1.00
AP6	Colorants, dyes & pigments	0.85	0.80	1.00	0.90	1.00	1.00	1.00	1.00	1.00
AP7	Flame Retardants	0.50	0.50	1.00	0.80	0.50	0.50	1.00	1.00	1.00
AP8	Fluorescent Whitening Agents	0.80	0.75	1.00	0.90	1.00	1.00	1.00	1.00	1.00
AP9	High-Polymer Additives	0.90	0.90	1.00	0.90	0.85	0.85	1.00	1.00	1.00
AP10	Metal Deactivators	0.75	0.75	1.00	0.90	0.95	0.95	1.00	1.00	1.00
AP11	Nucleating Agents	0.90	0.90	1.00	0.90	0.85	0.85	1.00	1.00	1.00
AP12	Plasticizers	0.75	0.75	1.00	0.90	0.95	0.95	1.00	1.00	1.00
AP13	Heat Stabilizers	0.50	0.50	1.00	0.90	0.50	0.50	1.00	1.00	1.00
AP14	Lead Heat Stabilizers	0.50	0.50	0.75	0.90	0.50	0.50	1.00	0.50	1.00
AP15	UV / Light Stabilizers	0.80	0.75	1.00	0.90	1.00	1.00	1.00	1.00	1.00
AP16	Paints, water based	0.30	0.60	0.90	0.90	0.75	0.80	1.00	1.00	1.00
AP17	Paints, solvent based	0.20	0.30	0.90	0.90	0.75	0.80	1.00	1.00	1.00
AP18	Paints, rubberized	0.30	0.60	0.90	0.90	0.75	0.80	1.00	1.00	1.00
AP19	Metal Coatings	0.30	0.60	0.75	0.90	0.75	0.75	1.00	1.00	1.00
AP20	Water Soluble Adhesives	0.90	0.90	0.90	0.90	0.90	0.90	1.00	1.00	1.00
AP21	Non-Water Soluble Adhesives	0.25	0.25	0.90	0.90	0.90	0.90	1.00	1.00	1.00
AP22	Lables, compatable plastic	0.95	0.95	0.90	0.90	1.00	1.00	1.00	1.00	1.00
AP23	Lables, incompatable plastic	0.25	0.25	0.90	0.90	1.00	1.00	1.00	1.00	1.00
AP24	Lables, paper	0.50	0.90	0.90	0.90	1.00	1.00	1.00	1.00	1.00
AP25	Fibers & Reinforcements	0.25	0.15	0.75	0.90	0.60	0.60	1.00	1.00	1.00
AP26	Fillers & Reinforcements	0.25	0.15	0.75	0.90	0.60	0.60	1.00	1.00	1.00

Metals Additive Table

	Coatings, Additives, Fillers	End-of-Life Effect Factors								
		Recycle			Reprocess				Landfill	
		recycled, without need for material segregation	recycled, segregation of co-mingled materials or special processing required	reground and used as part fillers	reprocessed chemically or thermally to recover basic material constituents	incineration used to recover heat energy and material	incineration used to recover heat energy and material, with toxic controls	unique process used for hazardous waste treatment	landfill / normal waste	landfill / hazardous waste
AM1	Ceramic	0.25	0.25	1.00	0.50	0.00	0.00	1.00	1.00	1.00
AM2	Metal Plating, Cadmium	0.80	0.80	0.25	0.75	0.00	0.00	1.00	0.00	1.00
AM3	Metal Plating, Chromium	0.90	0.90	0.25	0.75	0.00	0.00	1.00	1.00	1.00
AM4	Metal Plating, Cobalt	0.90	0.90	0.25	0.75	0.00	0.00	1.00	0.00	1.00
AM5	Metal Plating, Copper	0.90	0.90	1.00	0.75	0.00	0.00	1.00	1.00	1.00
AM6	Metal Plating, Gold	0.90	0.90	0.25	0.75	0.00	0.00	1.00	1.00	1.00
AM7	Metal Plating, Indium	0.90	0.90	0.25	0.75	0.00	0.00	1.00	0.00	1.00
AM8	Metal Plating, Iron	0.90	0.90	1.00	0.75	0.00	0.00	1.00	1.00	1.00
AM9	Metal Plating, Lead	0.75	0.75	0.25	0.75	0.00	0.00	1.00	0.00	1.00
AM10	Metal Plating, Nickel	0.90	0.90	1.00	0.75	0.00	0.00	1.00	1.00	1.00
AM11	Metal Plating, Palladium	0.90	0.90	1.00	0.75	0.00	0.00	1.00	1.00	1.00
AM12	Metal Plating, Platinum	0.90	0.90	1.00	0.75	0.00	0.00	1.00	1.00	1.00
AM13	Metal Plating, Rhodium	0.90	0.90	0.25	0.75	0.00	0.00	1.00	1.00	1.00
AM14	Metal Plating, Silver	0.90	0.90	0.25	0.75	0.00	0.00	1.00	1.00	1.00
AM15	Metal Plating, Tin	0.90	0.90	1.00	0.75	0.00	0.00	1.00	1.00	1.00
AM16	Metal Plating, Zinc	0.90	0.90	0.25	0.75	0.00	0.00	1.00	1.00	1.00
AM17	Annodizing	0.90	0.90	1.00	0.75	0.00	0.00	1.00	1.00	1.00
AM18	Adhesives	0.90	0.90	1.00	0.75	0.75	1.00	1.00	1.00	1.00
AM19	Lables	0.90	0.90	1.00	0.75	1.00	1.00	1.00	1.00	1.00
AM20	Phosphate Coating	0.85	0.85	0.50	0.75	0.00	0.00	1.00	1.00	1.00
AM21	Porcelain enameling	0.85	0.85	1.00	0.75	0.00	0.00	1.00	1.00	1.00
AM25	Paints	0.85	0.85	1.00	0.75	0.75	1.00	1.00	1.00	1.00
AM27	Impregnation, oil	0.75	0.75	0.50	0.75	1.00	1.00	1.00	0.75	1.00
AM28	Impregnation, resin	0.50	0.50	0.50	0.75	1.00	1.00	1.00	1.00	1.00

Misc. Additive Table

	Coatings, Additives, Fillers	End-of-Life Effect Factors: Recycle: recycled, without need for material segregation	Recycle: recycled, segregation of co-mingled materials or special processing required	Recycle: reground and used as part fillers	Reprocess: reprocessed chemically or thermally to recover basic material constituents	Reprocess: incineration used to recover heat energy and material	Reprocess: incineration used to recover heat energy and material, with toxic controls	Reprocess: unique process used for hazardous waste treatment	Landfill: landfill / normal waste	Landfill: landfill / hazardous waste
AC1	Adhesives	0.70	0.70	1.00	1.00	1.00	1.00	1.00	1.00	1.00
AC2	Chemical staining	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00
AC3	Colorants	0.70	0.70	1.00	1.00	1.00	1.00	1.00	1.00	1.00
AC4	Paints, vitreous enamels	0.50	0.50	1.00	1.00	0.85	1.00	1.00	0.85	1.00
AC5	Paints, laquers	0.50	0.50	1.00	1.00	0.85	1.00	1.00	0.85	1.00
AC6	Lead Paint	0.50	0.50	1.00	1.00	0.85	0.75	1.00	0.25	1.00
AC7	Lables	0.70	0.70	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Group Compatability Table

	Combination	End-of-Life Effect Factors: Recycle: recycled, without need for material segregation	Recycle: recycled, segregation of co-mingled materials or special processing required	Recycle: reground and used as part fillers	Reprocess: reprocessed chemically or thermally to recover basic material constituents	Reprocess: incineration used to recover heat energy and material	Reprocess: incineration used to recover heat energy and material, with toxic controls	Reprocess: unique process used for hazardous waste treatment	Landfill: landfill / normal waste	Landfill: landfill / hazardous waste
PM	Plastics / Metals	0.00	0.85	0.50	0.75	0.25	0.25	0.50	1.00	1.00
MP	Metals / Plastics	0.50	0.85	0.50	0.75	0.00	0.00	0.50	1.00	1.00
PC	Plastics / Miscellaneous	0.00	0.50	0.50	0.75	0.50	0.50	0.50	1.00	1.00
CP	Miscellaneous / Plastics	0.00	0.50	0.50	0.75	0.50	0.50	0.50	1.00	1.00
MC	Metals / Miscellaneous	0.50	0.85	0.50	0.75	0.00	0.00	0.50	1.00	1.00
CM	Miscellaneous / Metals	0.00	0.85	0.50	0.75	0.25	0.25	0.50	1.00	1.00

Plastics Compatability Table (Recycling)

		P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19
		ABS	ASA, SAN	EPM / EPDM	HDPE	LDPE	PA	PBT	PC	PEI	PET	PMMA	POM	PP	PPE, S-B	PPO	PS	PVC	SBS	TPU
P1	ABS	1																		
P2	ASA, SAN	1	1																	
P3	EPM / EPDM	0	0	1																
P4	HDPE	0	0	0	1															
P5	LDPE	0	0	0	1	1														
P6	PA	0	0	1	0	0	1													
P7	PBT	0	0.25	0	0	0	0	1												
P8	PC	0.75	0.75	0	0	0	0	1	1											
P9	PEI	0	0	0	0	0	0	0	0.5	1										
P10	PET	0	0	0	0	0	0.25	0.25	1	0	1									
P11	PMMA	0.75	0.75	0	0	0	0	0	1	0	0	1								
P12	POM	0	0	0	0	0	0	0	0	0	0	0	1							
P13	PP	0	0	1	0	0	0	0	0	0	0	0	0	1						
P14	PPE, S-B	0	0	0	0	0	0	0	0	0	0	0	0	0	1					
P15	PPO	0	0.25	0	0	0	0	0	0	0	0	0	0	0	0	1				
P16	PS	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1			
P17	PVC	0.25	0.75	0	0	0	0	0	0	0	0	0.75	0	0	0	0	0	1		
P18	SBS	0.75	0.25	0	0	0	0.25	0	0	0	0	0	0	0	0	0	1	0.25	1	
P19	TPU	1	1	0	0	0	0	0	0.25	0	0	0.25	0	0	0	0	0	0	0	1

Ratings: (range from 1 to 0) 1 - most compatable 0 - not compatable

Case Study of IBM PS/2 Computer

PART NAME	Primary Material	Second Material	Third Material	Fourth Material	Coatings, Additives, Fillers	Coatings, Additives, Fillers	Coatings, Additives, Fillers	End-of-Life Preferences								
								Recycle			Reprocess				Landfill	
								recycled, without need for material segregation	recycled, segregation of co-mingled materials or special processing required	reground and used as part fillers	reprocessed chemically or thermally to recover basic material constituents	incineration used to recover heat energy and material	incineration used to recover heat energy and material, with toxic controls	unique process used for hazardous waste treatment	landfill / normal waste	landfill / hazardous waste
C-Drive	M7	P8	D7					47.5	72.3	25.0	56.3	0.0	0.0	15.0	85.0	40.0
A-Drive	M8	P9	D8					42.5	63.8	0.0	56.3	0.0	0.0	15.0	80.0	40.0
C-Drive Controller	D7							75.0	75.0	50.0	90.0	70.0	60.0	75.0	85.0	40.0
Power Sup Screws	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Power Supply	M1	P1	D7	D8				45.0	76.5	25.0	56.3	0.0	0.0	15.0	80.0	40.0
Mother Board Screws	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Mother Board	D7							75.0	75.0	50.0	90.0	70.0	60.0	75.0	85.0	40.0
Cover Thumb Screws	M1	P8						45.0	76.5	25.0	56.3	0.0	0.0	15.0	80.0	40.0
Slot Covers	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Slot Cover Holder	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Plastic Bracket	P1							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Nut	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Star Washer	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Locking Bracket	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Lock Retainer Clip	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Lock	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Lock Position Ring	P8							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Steel Wool Inserts	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Threaded Inserts	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Rubber Feet	P3							50.0	40.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Base	P8				AP4	AP19	AP22	14.0	14.3	32.4	42.5	47.8	38.3	30.0	85.0	40.0
Locking Pin	P8							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Locking Pin Capture	P8							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0

Case Study of IBM PS/2 Computer (Cont. 2)

								End-of-Life Preferences: Recycle			End-of-Life Preferences: Reprocess				End-of-Life Preferences: Landfill	
PART NAME	Primary Material	Second Material	Third Material	Fourth Material	Coatings, Additives, Fillers	Coatings, Additives, Fillers	Coatings, Additives, Fillers	recycled, without need for material segregation	recycled, segregation of co-mingled materials or special processing required	reground and used as part fillers	reprocessed chemically or thermally to recover basic material constituents	incineration used to recover heat energy and material	incineration used to recover heat energy and material, with toxic controls	unique process used for hazardous waste treatment	landfill / normal waste	landfill / hazardous waste
Cooling Fan ssy	P8	P1	D7	M12	AP22			0.0	40.4	27.0	50.6	18.8	15.0	15.0	85.0	40.0
A-Drive Cntrlr Lock	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
A-Drive Controller	D7							75.0	75.0	50.0	90.0	70.0	60.0	75.0	85.0	40.0
Locking Pins	P8							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Locking Pin Capture	P8							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Drive Bracket	P8				AP4	AP2	AP19	13.2	13.5	36.0	44.9	40.6	32.5	30.0	85.0	40.0
A-Drive Covers	P8							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Face Plate	P8				AP16			21.0	30.0	54.0	67.5	56.3	48.0	30.0	85.0	40.0
Cover Base	M1				AM19	AM25		68.9	68.9	50.0	42.2	0.0	0.0	30.0	80.0	40.0

Case Study of 1995 GM Truck Dashboard

PART NAME	Primary Material	Second Material	Third Material	Fourth Material	Coatings, Additives, Fillers	Coatings, Additives, Fillers	Coatings, Additives, Fillers	End-of-Life Preferences								
								Recycle			Reprocess				Landfill	
								recycled, without need for material segregation	recycled, segregation of co-mingled materials or special processing required	reground and used as part fillers	reprocessed chemically or thermally to recover basic material constituents	incineration used to recover heat energy and material	incineration used to recover heat energy and material, with toxic controls	unique process used for hazardous waste treatment	landfill / normal waste	landfill / hazardous waste
Temp Ctrl/HVAC	P8	P5	P1	D7				0.0	25.0	30.0	56.3	37.5	30.0	15.0	85.0	40.0
screws (clust ssy)	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Instrument Cluster	P1	P8	D7	M15				0.0	42.5	30.0	56.3	18.8	15.0	15.0	85.0	40.0
Dome Light switch	P1							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Cargo Lamp switch	P1							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Instrument Bezel	P8	P13	P1	M1				0.0	42.5	30.0	56.3	18.8	15.0	15.0	85.0	40.0
Compartment	P1	P13	M1					0.0	42.5	30.0	56.3	18.8	15.0	15.0	85.0	40.0
Air outlet duct	P1							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Screws (duct ssy)	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Duct	P13							80.0	60.0	60.0	75.0	80.0	65.0	30.0	85.0	40.0
Drv door sens mnt	P1	M1						0.0	42.5	30.0	56.3	18.8	15.0	15.0	85.0	40.0
Sensor spring	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Pass door sens mnt	P1	M1						0.0	42.5	30.0	56.3	18.8	15.0	15.0	85.0	40.0
Sensor spring	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Black Gum Tape	P24							25.0	25.0	50.0	60.0	50.0	50.0	30.0	85.0	40.0
Remove wire	D9							75.0	75.0	50.0	90.0	70.0	60.0	75.0	85.0	40.0
Screw (fuse box)	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Screw (ground)	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Screw (Str col)	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Wire Harness	D9							75.0	75.0	50.0	90.0	70.0	60.0	75.0	85.0	40.0
Emerg. Brake Hndl.	P6							50.0	40.0	60.0	75.0	80.0	65.0	30.0	85.0	40.0
Emerg. Brake Cable	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Fuse Block Cover	P1	M1			AP24			0.0	38.3	27.0	50.6	18.8	15.0	15.0	85.0	40.0

Case Study of 1995 GM Truck Dashboard (Cont. 2)

								End-of-Life Preferences								
								Recycle			Reprocess				Landfill	
PART NAME	Primary Material	Second Material	Third Material	Fourth Material	Coatings, Additives, Fillers	Coatings, Additives, Fillers	Coatings, Additives, Fillers	recycled, without need for material segregation	recycled, segregation of co-mingled materials or special processing required	reground and used as part fillers	reprocessed chemically or thermally to recover basic material constituents	incineration used to recover heat energy and material	incineration used to recover heat energy and material, with toxic controls	unique process used for hazardous waste treatment	landfill / normal waste	landfill / hazardous waste
Drv Side Foam	P20							0.0	0.0	60.0	75.0	80.0	65.0	30.0	85.0	40.0
Duct RH	P1							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Pass Side Foam	P20							0.0	0.0	60.0	75.0	80.0	65.0	30.0	85.0	40.0
Rubber Dash Cush.	P23							0.0	0.0	60.0	60.0	30.0	50.0	30.0	85.0	40.0
Bolster Screws	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Knee Bolster ssy	P1	P8	P16	P13				0.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Cup Holder Retainer	P1							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Cup Holder ssy	P1	M1	P3	P8	AP24			0.0	38.3	27.0	50.6	18.8	15.0	15.0	85.0	40.0
Mounting Spikes	P1							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Retainer Clip	P1							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Ash Tray ssy	P1	M1	P24	P23				0.0	42.5	30.0	56.3	18.8	15.0	15.0	85.0	40.0
Defl. ssy, out	P1	P13						0.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Defl. ssy, in	P1	P13						0.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Track Screws	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Drink Hol Slide Trck	M1							90.0	90.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Plas. Wrapper, sm	P1							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Plas. Wrapper, lg	P1							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Nut-I/P Carrier	M15							90.0	85.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0
Comp I/P Cluster	P13							80.0	60.0	60.0	75.0	80.0	65.0	30.0	85.0	40.0
Plunger	P1							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Plunger Base	P1							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Liner ssy	P3							50.0	40.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Nut I/P Carrier	M15							90.0	85.0	50.0	75.0	0.0	0.0	30.0	80.0	40.0

Case Study of 1995 GM Truck Dashboard (Cont. 3)

								End-of-Life Preferences								
								Recycle			Reprocess				Landfill	
PART NAME	Primary Material	Second Material	Third Material	Fourth Material	Coatings, Additives, Fillers	Coatings, Additives, Fillers	Coatings, Additives, Fillers	recycled, without need for material segregation	recycled, segregation of co-mingled materials or special processing required	reground and used as part fillers	reprocessed chemically or thermally to recover basic material constituents	incineration used to recover heat energy and material	incineration used to recover heat energy and material, with toxic controls	unique process used for hazardous waste treatment	landfill / normal waste	landfill / hazardous waste
Vent Base (2)	P1							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Rubber Cup Mat	P23							0.0	0.0	60.0	60.0	30.0	50.0	30.0	85.0	40.0
Flow Director	P1							70.0	50.0	60.0	75.0	75.0	60.0	30.0	85.0	40.0
Vent Base	P13							80.0	60.0	60.0	75.0	80.0	65.0	30.0	85.0	40.0

Appendix B: Potential Use of Recycled Plastics in Manufacturing Processes

Material Specifications

- Check List of Material Requirements:

Material Description:

			Critical (✓ Yes)	Required Values	Actual Values	ASTM Test Method
Processing	Melt Flow (gm./10min.)					D1238
	Melting Temperature (°C)	T_m (crystalline)				
		T_g (amorphous)				
	Processing Temperature Range (°F) (C = compression; I = injection; T = transfer; E = extrusion)					
	Molding Pressure Range (10^3 psi)					
	Compression Ratio					
	Mold (Linear) Shrinkage (in/ in)					D955
Mechanical	Tensile Strength at Break (psi)					D638, D412, D882
	Elongation at Break (%)					D638
	Tensile Yield Strength (psi)					D638
	Compressive Strength (rupture or yield; psi)					D695
	Flexural Strength (rupture or yield) (psi)					D790
	Tensile Modulus (10^3 psi)					D638
	Compressive Modulus (10^3 psi)					D695
	Flexural Modulus (10^3 psi)	73° F				D790
		200° F				D790
		250° F				D790
		300° F				D790
	Creep Modulus / Creep Rupture					D2990
	Izod Impact ($^1/_8$ - in thick spec.; ft-lb/in of notch)					D256A
	Hardness	Rockwell				D785
		Shore/Barcol				D2240, D2583
	Abrasion Resistance (volume loss, cm^3)					D1242
Thermal	Coef. of Linear Thermal Expan. (10^{-6} in/in/°C)					D696, D596
	Deflection Temperature	264 psi				D648
	Under Flexural Load (°F)	66 psi				D648
	Thermal Conductivity (10^{-4} cal cm/sec cm^2 °C)					C177
	Vicat Softening Temp. (°F)	Rate A				D1525
		Rate B				
Physical	Specific Gravity					D792
	Water Absorption (%)	24 hr				D570
	($^1/_8$ - in thick specimen)	Saturation				D570
	Dielectric Strength, short time, (v./mil)					D149
Misc.	Material Color					D1729 (vol. 06.01)
	Chemical Resistance					D543
	FDA Approved Material					(FDA Regulations)
	Contamination Specifications					
	Other					

- When it is necessary to test the material against the requirements above, use performance tests that are best suited to the material application.

- The last column in the chart above contains recommended ASTM tests, where applicable.
  Note: D256 to D2343 located in volume 08.01, D2383 to D4322 located in volume 08.02

Process Testing Procedure - Extrusion

Trial Set-Up

1. Identify materials to be used. Document the material's identification and description on the Process Specifications for Extrusion form as well as important material characteristics for the process. If material is to be ordered, make sure the lead time fits the time frame of the trial.
2. Collect information from past experience to estimate the required time to run each trial. The information should include times for cleaning and filling the hopper, equipment warm-up, start-up of the extrusion line, purge time to remove any material in the extruder, and time for the line to stabilize. It is better to over-estimate these times than to under-estimate them.
3. Determine the blend of materials to be used for each trial. The number of blends will relate to the number of trials. Starting with the minimum targeted recycled content level, increase the percentage of recycled material in the blend by increments of 10 - 20% depending on the number of trials. For each blend determine the approximate starting machine conditions (temperature, pressure, and amperage). Assign trial numbers.
4. Make sure the form to document the Process Specifications for Extrusion is available as well as marking pens or flags to identify sections of the extrusion to be tested, a tape measure, and anything else to be used during the tests.
5. Make sure all operators and test personnel involved have a good understanding of the trial and their responsibilities.
6. Plan to clean the feed hopper and transport equipment during start-up so that the purge time is minimized.
7. Record the equipment information on the Process Specifications for Extrusion form.
8. Record baseline processing conditions and extrusion test characteristics for standard products to be used for comparison during trials.

Start-Up

1. Material Preparation
   a) Weigh each material as accurately as the equipment allows, record weights, calculate percentage of each material, and note any comments.
   b) Mix materials so the blend of the materials fed to the extruder hopper is homogeneous. Record time and any comments.
   c) Make sure the hopper and feeding equipment are clean, then load hopper.
2. Line Start-up
   a) Using the start-up conditions determined during the trial set-up, start the extrusion line
   b) The temperatures and extruder RPM may need to be adjusted to achieve the desired extruder amperage, extruder pressure and throughput.
3. Purge all material left in the extruder. This will stabilize the line and test results will reflect actual trial blends.
4. Once the line is running and equipment has stabilized, take all machine measurements and measure the dimensions of the extrusion.

Process Run

1. Adjust temperature settings and other machine variables to stabilize the extrusion line. Record any machine line changes and record machine variables throughout the trial. Take the appropriate measurements of the extrusion every 5 -10 minutes. Record machine conditions.
2. If multiple thicknesses are to be run, increase or decrease line speed for the new thickness. Record all machine conditions and re-measure thickness.
3. Mark the extrusion (paper flag or marking pen) when changing variables or pull samples for each extrusion section for testing. Note on log sheet so machine conditions can be compared to test results.
4. Note the characteristics of the extrusions and any comments from the operators on how the material compares to standard processing.

Process Specifications for Extrusion

Company:
Date:
Trial #:

Machine Type:
Die Size:
Die Gap:

Screw Length:
Screw L/D:

Material Description	***Weight***	***Percentage***	***Vendor***	***Lot #***	***Comments***
Total					

Mixing Time:

Comments:

Process Testing Data Chart:

Time	*Extrusion Thickness*	*Temp.*	*Temp.*	*Temp.*	*Temp.*	*Temp.*	*Temp.*	*Amps*	*RPM*	*Pull Speed*	*Die / Extruder Pressure*	*Throughput*	*Comments*

Comments: ______________________________

Process Testing Procedure - Thin Film / Sheet Extrusion

Trial Set-Up

1. Identify materials to be used. Document the material's identification and description on the Process Specifications for Thin Film / Sheet form as well as the important material characteristics for the process. If material is to be ordered, make sure the lead time fits the time frame of the trial.
2. Collect information from past experience to estimate the required time to run each trial. The information should include times for cleaning and filling the hopper, equipment warm-up, start-up of the film line, purge time to remove any material in the extruder and time for the line to stabilize. It is better to over-estimate these times than to under-estimate them.
3. Determine the blend of materials to be used for each trial. The number of blends will relate to the number of trials. Starting with the minimum targeted recycled content level, increase the percentage of recycled material in the blend by increments of 10 - 20% depending on the number of trials. For each blend determine the approximate starting machine conditions (temperature, pressure, amperage, and air flow). Assign trial numbers.
4. Make sure the form to document the Process Specifications for Thin Film / Sheet is available as well as marking pens or flags to identify sections of film to be tested, a tape measure, and anything else to be used during the tests.
5. Make sure all operators and test personnel involved have a good understanding of the trial and their responsibilities.
6. Plan to clean the hopper and transport equipment during start-up so purge time is minimized.
7. Record the equipment information on the Process Specifications for Thin Film/Sheet form.
8. Record baseline processing conditions and film test characteristics for standard products to be used for comparison during trials.

Start-Up

1. Material Preparation
    a) Weigh each material as accurately as the equipment allows, record weights, calculate percentage of each material, and note any comments.
    b) Mix materials so the blend of the materials fed to the extruder hopper is homogeneous. Record time and any comments.
    c) Make sure hopper and feeding equipment are clean, then load hopper.
2. Line Start-up
    a) Using the start-up conditions determined during the trial set-up, start the film line
    b) The temperatures and extruder RPM may need to be adjusted to achieve the desired extruder amperage, extruder pressure and throughput.
3. Purge all material left in the extruder. This will stabilize the line and test results will reflect actual trial blends.
4. Once the line is running and equipment has stabilized, take all machine measurements and measure film thickness.

Process Run

1. Adjust temperature and air flow settings to stabilize the film line. Record any machine line changes and record machine variables throughout the trial. Measure the film thickness using the trimmed material every 5 -10 minutes. Record machine conditions.
2. If multiple thicknesses are to be run, increase or decrease line speed for the new thickness. Record all machine conditions and re-measure thickness.
3. Mark the roll (paper flag or marking pen) when changing variables or pull samples for each film section for testing. Note on log sheet so machine conditions can be compared to test results.
4. Note film smoothness, printability, and any other comments from the operators on how the material compares to standard processing.

Process Specifications for Thin Film / Sheet

Company:
Date:
Trial #:

Machine Type:
Die Size:
Die Gap:

Screw Length:
Screw L/D:

Material Description	***Weight***	***Percentage***	***Vendor***	***Lot #***	***Comments***
Total					

Mixing Time:

Comments:

Process Testing Data Chart:

Time	***Film Thickness***	***Temp.***	***Temp.***	***Temp.***	***Temp.***	***Temp.***	***Temp.***	***Amps***	***RPM***	***Pull Speed***	***Frostline Height***	***Die / Extruder Pressure***	***Throughput***	***Comments***

Comments:

Process Testing Procedure - Blown Film Extrusion

Trial Set-Up

1. Identify materials to be used. Document the material's identification and description on the Process Specifications for Blown Film form as well as important material characteristics for the process. If material is to be ordered, make sure the lead time fits the time frame of the trial.
2. Collect information from past experience to estimate the required time to run each trial. The information should include times for cleaning and filling the hopper, equipment warm-up, start-up of the film line, purge time to remove any material in the extruder, and time for the line to stabilize. It is better to over-estimate these times than to under-estimate them.
3. Determine the blend of materials to be used for each trial. The number of blends will relate to the number of trials. Starting with the minimum targeted recycled content level, increase the percentage of recycled material in the blend by increments of 10 - 20% depending on the number of trials. For each blend determine the approximate starting machine conditions (temperature, pressure, amperage, and air flow). Assign trial numbers.
4. Make sure the Process Specifications for Blown Film form is available to document the process as well as marking pens or flags to identify sections of film to be tested, a tape measure, and anything else to be used during the tests.
5. Make sure all operators and test personnel involved have a good understanding of the trial and their responsibilities.
6. Plan to clean hopper and transport equipment during start-up so purge time is minimized.
7. Record the equipment information on the Process Specifications for Blown Film form.
8. Record baseline processing conditions and film test characteristics for standard products to be used for comparison during trials.

Start-Up

1. Material Preparation
    a) Weigh each material as accurately as the equipment allows, record weights, calculate percentage of each material, and note any comments.
    b) Mix materials so the blend of the materials fed to the extruder hopper is homogeneous. Record time and any comments.
    c) Make sure hopper and feeding equipment are clean, then load hopper.
2. Line Start-up
    a) Using the start-up conditions determined during the trial set-up, start the film line
    b) The temperatures and extruder RPM may need to be adjusted to achieve the desired extruder amperage, extruder pressure and throughput.
3. Purge all material left in the extruder. This will stabilize the line and test results will reflect actual trial blends.
4. Once the line is running and equipment has stabilized, take all machine measurements and measure film thickness.

Process Run

1. Adjust temperature and air flow settings to stabilize the film line. Record any machine line changes and record machine variables throughout the trial. Measure the film thickness every 5 -10 minutes. Record machine conditions.
2. If multiple thicknesses are to be run, increase or decrease line speed for the new thickness. Record all machine conditions and re-measure thickness.
3. The frost line height may have an effect on strength. Fluctuating frost line heights can be compensated for by adjusting temperatures, throughput, or airflow.
4. Mark the roll (paper flag or marking pen) when changing variables or pull samples for each film section for testing. Note on log sheet so machine conditions can be compared to test results.
5. Note film smoothness, frost line height and stability, printability, and any other comments from the operators on how the material compares to standard processing.

Process Specifications for Blown Film

Company:
Date:
Trial #:

Machine Type:
Die Size:
Die Gap:

Blow-up Ratio:
Screw Length:
Screw L/D:

Material Description	***Weight***	***Percentage***	***Vendor***	***Lot #***	***Comments***
Total					

Mixing Time:

Comments:

Process Testing Data Chart:

Time	***Film Thickness***	***Temp.***	***Temp.***	***Temp.***	***Temp.***	***Temp.***	***Temp.***	***Amps***	***RPM***	***Air Pressure***	***Air Flow Rate***	***Pull Speed***	***Frostline Height***	***Die / Extruder Pressure***	***Throughput***	***Comments***

Comments:

Process Testing Procedure - Extrusion Blow Molding

Trial Set-Up

1. Identify materials to be used. Document the material's identification and description on the Process Specifications for Extrusion Blow Molding form as well as important material characteristics for the process. If material is to be ordered, make sure the lead time fits the time frame of the trial.
2. Collect information from past experience to estimate the required time to run each trial. The information should include times for cleaning and filling the hopper, equipment warm-up, start-up of the extrusion / blow molding line, purge time to remove any material in the extruder, and time for the line to stabilize. It is better to over-estimate these times than under-estimate them.
3. Determine the blend of materials to be used for each trial. The number of blends will relate to the number of trials. Starting with the minimum targeted recycled content level, increase the percentage of recycled material in the blend by increments of 10 - 20% depending on the number of trials. For each blend determine the approximate starting machine conditions (temperature, pressure, amperage, and air flow / pressure). Assign trial numbers.
4. Make sure the form to document the Process Specifications for Extrusion Blow Molding is available as well as marking pens or flags to identify the blow moldings to be tested and anything else to be used during the tests.
5. Make sure all operators and test personnel involved have a good understanding of the trial and their responsibilities.
6. Plan to clean hopper and transport equipment during start-up so purge time is minimized.
7. Record equipment information on Process Specifications for Extrusion Blow Molding form.
8. Record baseline processing conditions and blow molding test characteristics for standard products to be used for comparison during trials.

Start-Up

1. Material Preparation
   a) Weigh each material as accurately as the equipment allows, record weights, calculate percentage of each material, and note any comments.
   b) Mix materials so the blend of the materials fed to the extruder hopper is homogeneous. Record time and any comments.
   c) Make sure hopper and feeding equipment are clean, then load hopper.
2. Line Start-up
   a) Using the start-up conditions determined during the trial set-up, start the extrusion line and bring the blow molds to their proper temperature.
   b) The temperatures and extruder RPM may need to be adjusted to achieve the desired extruder amperage, extruder pressure and throughput.
3. Purge all material left in the extruder. This will stabilize the line and test results will reflect actual trial blends.
4. Once the line is running and equipment has stabilized, take all machine measurements and measure wall thickness and diameter of the parison (tube of plastic material).

Process Run

1. Adjust temperatures and air flow to stabilize the extrusion line. Record any machine line changes and record machine variables throughout the trial. Take the appropriate measurements every 5 -10 minutes. Record machine conditions.
2. If multiple thicknesses are to be run, increase or decrease line speed for the new thickness. Record all machine conditions and re-measure thickness.
3. Mark the blow molded parts (paper flag or marking pen) when changing variables' or pull samples for each extrusion section for testing. Note on log sheet so machine conditions can be compared to test results.
4. Note the wall thickness, thickness variation, part weight, and any other comments from the operators on how the material compares to standard processing.

Process Specifications for Extrusion Blow Molding

Company:
Date:
Trial #:

Machine Type:
Die Size:
Die Gap:

Blow-up Ratio:
Screw Length:
Screw L/D:

Material Description	*Weight*	*Percentage*	*Vendor*	*Lot #*	*Comments*
Total					

Mixing Time:

Comments:

Process Testing Data Chart:

Time	*Wall Thickness*	*Temp.*	*Temp.*	*Temp.*	*Temp.*	*Temp.*	*Temp.*	*Amps*	*RPM*	*Air Pressure*	*Air Flow Rate*	*Pull Speed*	*Die / Extruder Pressure*	*Throughput*	*Cycle Time*	*Comments*

Comments:

Process Testing Procedure - Injection Molding

Trial Set-Up

1. Identify materials to be used. Document the material's identification and description on the Process Specifications for Injection Molding form as well as the important material characteristics for the process. If material is to be ordered, make sure the lead time fits the time frame of the trial.
2. Collect information from past experience to estimate the required time to run each trial. The information should include times for cleaning and filling the hopper, equipment warm-up, complete molding cycle time, and purge time to remove any material in the injector. It is better to over-estimate these times than to under-estimate them.
3. Determine the blend of materials to be used for each trial. The number of blends will relate to the number of trials. Starting with the minimum targeted recycled content level, increase the percentage of recycled material in the blend by increments of 10 - 20% depending on the number of trials. For each blend determine the approximate starting machine conditions (temperature, pressure, and amperage). Assign trial numbers.
4. Make sure the form to document the Process Specifications for Injection Molding is available as well as marking pens or flags to identify the molded parts to be tested, and anything else to be used during the tests.
5. Make sure all operators and test personnel involved have a good understanding of the trial and their responsibilities.
6. Plan to clean the feed hopper and transport equipment during start-up so that the purge time is minimized.
7. Record the equipment information on the Process Specifications for Injection Molding form.
8. Record baseline processing conditions and test characteristics for the standard injection molded products to be used for comparison during trials.

Start-Up

1. Material Preparation
   a) Weigh each material as accurately as the equipment allows, record weights, calculate percentage of each material, and note any comments.
   b) Mix materials so the blend of the materials fed to the injection hopper is homogeneous. Record time and any comments.
   c) Make sure hopper and feeding equipment are clean, then load hopper.
2. Line Start-up
   a) Using the start-up conditions determined during the trial set-up, start the injection molding system and bring the molds to their proper temperature.
   b) The temperature settings and the RPM of the reciprocating screw may need to be adjusted to achieve the desired extruder amperage, injection pressure, and throughput.
3. Purge all material left in the reciprocating screw unit. This will stabilize the process and test the results will reflect actual trial blends.
4. Once the equipment has stabilized, take all of the machine measurements.

Process Run

1. Adjust temperatures and other parameters until they reach a steady state. Record any machine changes and record machine variables throughout the trial.
2. Mark the injection molded parts (paper flag or marking pen) when changing variables, or pull samples for each group of injection molded parts for testing. Note on log sheet so machine conditions can be compared to test the results.
3. Note the characteristics of the injection molded part and any other comments from operators on how the material compares to standard processing.

Process Specifications for Injection Molding

Company:
Date:
Trial #:

Machine Type:
Die Size:
Die Gap:

Reciprocating Screw Length:
Reciprocating Screw L/D:

Material Description	*Weight*	*Percentage*	*Vendor*	*Lot #*	*Comments*
Total					

Mixing Time:

Comments:

Process Testing Data Chart:

Time	*Temp.*	*Temp.*	*Temp.*	*Temp.*	*Temp.*	*Temp.*	*Amps*	*RPM*	*Injection Pressure*	*Throughput*	*Cycle Time*	*Comments*

Comments: ____

Process Testing Procedure - Injection Blow Molding *

Trial Set-Up *

* Before conducting this test procedure, the Process Testing Procedure for Injection Molding must first be conducted for the analysis of the injection molded preform.

1. Document the identification and description of the material used in the preform on the Process Specifications for Injection Blow Molding form, as well as important material characteristics for the process.
2. Collect information from past experience to estimate the required time to run each trial. The information should include times for equipment warm-up, start-up of the blow molder, and blow molding cycle time. It is better to over-estimate these times than under-estimate them.
3. For each blend used to make the preforms during the Process Test for Injection Molding, determine the approximate starting machine conditions (temperatures, pressure, amperage, and air flow / pressure). Assign trial numbers.
4. Make sure the form to document the Process Specifications for Injection Blow Molding is available as well as marking pens or flags to identify the blow moldings to be tested and anything else to be used during the tests.
5. Make sure all operators and test personnel involved have a good understanding of the trial and their responsibilities.
6. Record equipment information on the Process Specifications for Injection Blow Molding form.
7. Record baseline processing conditions and blow molding test characteristics for standard products to be used for comparison during trials.

Start-Up

1. Part Preparation - be sure the preforms properly identified to their material content.
2. Line Start-up - Using the start-up conditions determined during the trial set-up, start up the injection blow molding process and bring the blow molds to their proper temperatures.
3. Once the blow molding system is running and equipment has stabilized, take all machine measurements.

Process Run

1. Adjust temperatures and air flow as needed. Record any machine line changes and record machine variables throughout the trial. Take the appropriate measurements during the process. Record machine conditions.
2. If multiple thicknesses are to be run,. increase or decrease temperatures and air flow / pressure for the process. Record all machine conditions.
3. Mark the blow molded parts (paper flag or marking pen) when changing variables' or pull samples for each group of parts for testing. Note on log sheet so machine conditions can be compared to test results.
4. Note the wall thickness, thickness variation, part weight, and any other comments from the operators on how the material compares to standard processing.

Process Specifications for Injection Blow Molding

Company: Machine Type: Blow-up Ratio:
Date: Die Size: Screw Length:
Trial #: Die Gap: Screw L/D:

Material Description	***Weight***	***Percentage***	***Vendor***	***Lot #***	***Comments***
Total					

Mixing Time: Comments:

Process Testing Data Chart:

Time	*Wall Thickness*	*Temp.*	*Temp.*	*Temp.*	*Temp.*	*Temp.*	*Amps*	*Air Pressure*	*Air Flow Rate*	*Cycle Time*	*Comments*

Comments:

Product Specifications

- Check List of Product Requirements:

Material Description:		Critical (✓ Yes)	Required Values	Actual Values	ASTM Test Method
Blown Film, Thin Film, Sheet	Gel Count				D3351
	Tensile Strength (psi)				D882
	Tear / Shear Strength (psi)				D1004
	Dart Drop Impact Strength				D1709
	Haze / Color				D1746, D1003
	Gloss				D2457
	Dimensional Tolerance				
	Other				
Extrusion	Dimensional Tolerance				
	Wall Thickness				
	Thickness Variation				
	Part Weight				
	Aging / Weathering				D756
	Tensile Yield Strength (psi)				D638
	Torsional Yield Strength (psi)				
	Surface Texture / Quality				
	Color				
	Other				
Injection Molding	Drop Impact Resistance				
	Top Loading				
	Dimensional Tolerance				
	Part Weight				
	Aging / Weathering				D756
	Surface Texture / Quality				
	Color				
	Other				
Injection Blow Molding, Extrusion Blow Molding	Drop Impact Resistance				D2463
	Environment Stress Crack Resistance				D2561
	Dimensional Tolerance				D2911
	Wall Thickness				
	Thickness Variation				
	Part Weight				
	Part Stiffness				D149
	Aging / Weathering				D756
	Surface Texture / Quality				
	Color				
	Other				
Investment Casting Patterns	Melt Flow (gm./10min.)				D1238
	Melting Temperature (°C) T_m (crystalline)				
	T_g (amorphous)				
	Dimensional Tolerance				
	Viscosity				
	Other				

- When it is necessary to test the product against the requirements above, use performance tests that are best suited to the product application.

- The last column in the chart above contains recommended ASTM tests, where applicable.
  Note: D256 to D2343 located in volume 08.01, D2383 to D4322 located in volume 08.02

Bibliography

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